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MANUAL ON ENVIRONMENTAL MANAGEMENT FOR MOSQUITO CONTROL

WITH SPECIAL EMPHASIS ON MALARIA VECTORS



World
Health
Organization,
Geneva



MANUAL ON ENVIRONMENTAL MANAGEMENT FOR MOSQUITO CONTROL

with special emphasis on malaria vectors

COMMUNITY HEALTH CELL

47/1 St. Mark's Road, Bangalore – 560 001

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CONTENTS

	Page
Preface	7
Introduction	9
I. Mosquitos, mosquito-borne disease and mosquito control methods: a review	11
II. Environmental management for mosquito-borne disease control	28
III. Environmental modification	32
IV. Environmental manipulation	117
V. Reduction of man/mosquito contact	154
VI. Planning environmental management for mosquito control	165
VII. Practical guidelines for the vector control worker	174
Annex 1. Basic information on mosquito vectors and diseases	226
Annex 2. List of environmental management measures which have proved to be useful in the prevention and control of malaria and schistosomiasis	265
Annex 3. Matrix for the study and analysis of the environmental impact of a reservoir in a water resources development project	269
Annex 4. Checklist of major steps for the prevention and control of vector-borne diseases at each phase of water resources development projects	272
Annex 5. Equipment for environmental management	276

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PREFACE

The aim of this Manual is to provide information on environmental management techniques, methods and practices in the control of mosquito vectors of malaria and other diseases. It is intended in the first place to help vector control workers to familiarize themselves with these techniques, methods and practices, and to enable them to carry out simple environmental management works especially in the context of primary health care activities. Secondly the Manual can assist planners, designers and constructors of water resources development projects to appreciate the health implications of such projects and to design and operate them in ways that will prevent or reduce the introduction and spread of mosquito-borne diseases. The Manual can be used as a reference book in daily practice, for the training of staff, or for the preparation of staff manuals for use in vector control programmes and water resource development projects.

Some limitations in the scope of the Manual were unavoidable because of the lack of any comprehensive experience of the application of environmental management measures to control mosquito vectors of disease. Therefore, although the principles outlined are universally sound, adjustments to local conditions will be required in applying them.

Although the Manual deals principally with environmental management for the control of mosquito vectors, many of the works and operations described can be effectively used against certain other vectors. For the aspects of vector control not covered in the present work, reference should be made to other publications, several of which are included in the further reading lists at the end of the chapters or in Annex 1.

As experience accumulates with regard to environmental management operations and works throughout the world, it may be found that some subjects and details are lacking or insufficiently covered in this Manual. Any such deficiencies should be pointed out by letter to the Division of Vector Biology and Control, World Health Organization, 1211 Geneva 27, Switzerland. They will be gratefully acknowledged and included in any future edition.

Readers who are not experienced entomologists are sometimes confused by the correct practice of abbreviating the generic names of mosquito vectors to a single initial letter. In this book, therefore, a departure from the correct practice has been made in order to help them, a two-letter abbreviation being used for some genera: for example, Ae. for Aedes and An. for Anopheles, and Cs. for Culiseta and Cx for Culex.

INTRODUCTION

Environmental modification and manipulation for the control of mosquito vectors of disease almost disappeared with the development of chemical insecticides. After the Second World War, the use of such insecticides, especially as residual house sprays, was so efficacious in controlling mosquitos and mosquito-borne diseases that little or no use was made of biological and physical methods of mosquito control. However, starting with Culex molestus in Italy and Anopheles sacharovi in Greece, mosquitos of economic and public health importance began to develop resistance to insecticides and this slowed the advances made by chemical control alone. Furthermore, environmental concern over repeated applications of insecticides for pest or vector control has contributed to a decrease in the development of new public health insecticides. The recent oil price increases have narrowed the economic feasibility of repeated insecticide applications. At the same time the development and extended availability of skilled manpower and efficient excavating and earth-moving equipment increased the feasibility of applying large-scale environmental management measures for mosquito control. The need to develop integrated strategies including both old and new methods of mosquito control is now widely accepted. Environmental management measures constitute an effective component of such strategies.

It must be pointed out that the objective of environmental management for vector control is the reduction of the abundance of dangerous species. Past experience with mosquito vectors of disease has shown that each species has defined geographical distribution zones and occurs in large numbers only in certain breeding sites with identifiable combinations of physical, chemical and biological characteristics.

Environmental management measures thus depend on the fullest understanding of mosquito ecology and population dynamics as well as of mosquito-borne disease epidemiology. Studies on vector habitats must therefore be intensified in order that the attack may be made on sound bases.

An important concept is that of "species sanitation". This term, as applied to malaria control, means that attention should be directed primarily to local anopheline mosquitos known to be the principal transmitters of malaria. There are about 150 species of these potential malaria vectors in the world; only some 30 of them are considered to be important malaria vectors, and of the 30 only a few will occur locally in any given geographical area (see Table 1.2 - Annex 1). What could appear as an almost impossible task of controlling all anopheline mosquitos is thus narrowed down to a reasonably attainable goal.

How successfully man can intervene in the readjustment of habitats depends upon how well scientific inquiry in the field defines the key factors that regulate mosquito populations and favour the breeding of one kind of mosquito but not that of another. The vector control worker thus must explore the possibility of economic application of these principles so that the impoundments, irrigation, hydroelectric, fish culture and other man-made works, which are liable to become mosquito breeding places, may benefit man without producing an undue abundance of vectors.

Environmental management measures are not intended to replace other methods and techniques applied to control vector-borne diseases but rather to complement these and provide for the development of "integrated control" strategies (see Fig. 0-1).

At the same time, although some environmental management works and operations may in the long run be more effective and less expensive than other control measures, it may be difficult economically to justify their use for vector control purposes alone. Often, benefits obtained in other fields, such as the better use of water and land for agricultural improvement and extension derived from environmental management measures, provide additional justification. Sound environmental management, designed to avoid possible adverse consequences such as the breeding and multiplication of disease vectors, should be considered as an integral part of all engineering undertakings involving the modification and manipulation of the environment.

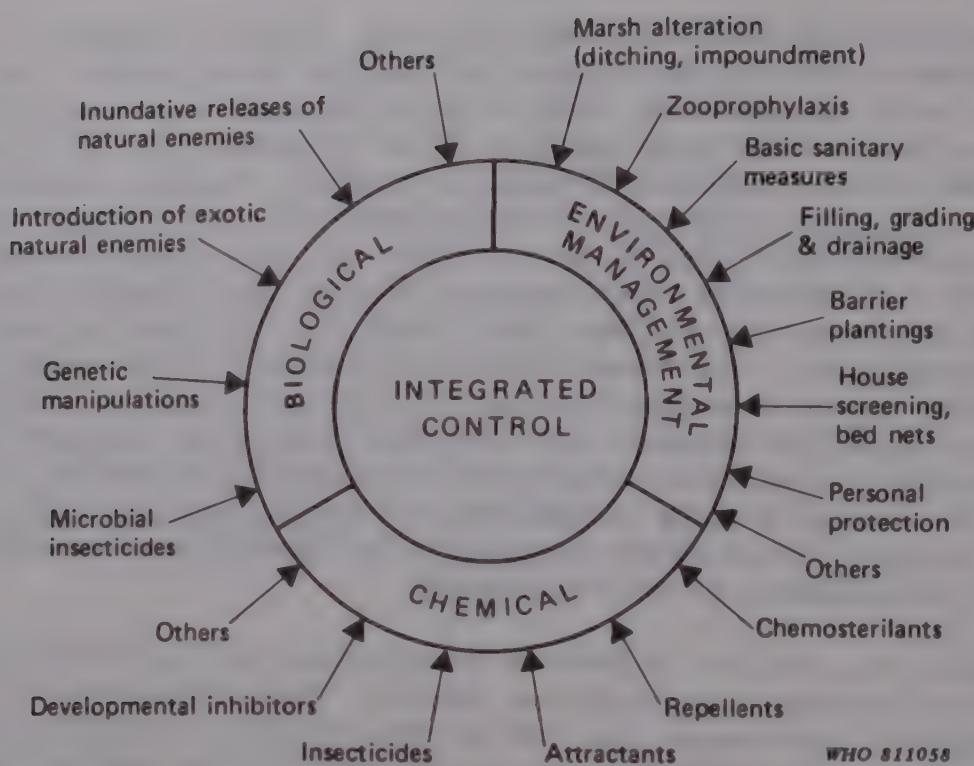


Fig. 0-1. Diagram of the components (environmental management, chemical, biological) and their potential constituent methods to be considered in an "integrated control" approach to mosquito control.

Adapted from: Axtell, R.C. Principles of integrated pest management (IPM) in relation to mosquito control. Mosquito News, 39: 709-718 (1979).

CHAPTER I

MOSQUITOS, MOSQUITO-BORNE DISEASE
AND MOSQUITO CONTROL METHODS: A REVIEW

CONTENTS

	<u>Page</u>
Introduction	11
1. Mosquitos and their bionomics	12
1.1 Classification, morphology and life cycle of the mosquito	12
1.2 Mosquito bionomics	14
1.2.1 The environment of the immature stages of the mosquito	14
1.2.2 The environment and habits of the adult mosquito	15
2. Major mosquito-borne diseases and their epidemiology	18
2.1 Malaria	18
2.2 Filariasis	19
2.3 Yellow fever	20
2.4 Dengue haemorrhagic fever	21
2.5 Encephalitis and other viral diseases	21
3. The available methods of mosquito control	22
3.1 Introduction	22
3.2 Chemical methods	22
3.2.1 Residual spraying	23
3.2.2 Larvicing	24
3.2.3 Space spray application	24
3.3 Biological methods	25
3.3.1 Introduction	25
3.3.2 Larvivorous fish	25
3.3.3 Invertebrate predators	25
3.3.4 Nematodes	26
3.3.5 Protozoa and fungi	26
3.3.6 Bacteria	26
3.4 Genetic control	26
3.5 Environmental management methods	26
4. Pest (nuisance) mosquitos and their control	26

Introduction

The aim of this chapter is to provide engineers and operators of development projects with some essential information on mosquito bionomics and classification and the relation of mosquitos to disease. A better understanding of these subjects will be useful to them and will facilitate their collaboration with the health staff.

In recent years, considerable environmental changes have taken place in many areas as a result of the creation of man-made lakes, the development of agricultural projects, deforestation, urbanization, and other economic development activities involving land and water use. As a consequence, the classical breeding habits of mosquito vectors and even some aspects of

their bionomics may also be changing in these areas. In any new development project or activity, therefore, the participation of entomologist staff in a multidisciplinary team should be sought in order that a precise picture may be obtained of current vector bionomics and behaviour, and their relation to human ecology and other prevailing environmental factors.

1. Mosquitos and their bionomics

1.1 Classification, morphology and life cycle of the mosquito

Mosquitos are two-winged insects belonging to the order Diptera, family Culicidae and subfamily Culicinae. They are characterized by having long conspicuous needle-shaped mouth-parts comprising the proboscis which, in the female, is used for sucking blood. Mosquitos are widely distributed over the world, the number of species exceeding 1500 and separated into two great divisions or tribes — the Anophelini and Culicini, the former being the smaller tribe but including the vectors of human malaria and filariasis. The Culicini include vectors of viral and filarial diseases of man and species of vicious biters, some of which are not incriminated in transmission of human disease.

The immature and adult stages of mosquitos are passed in two completely different environments. The immature stages (i.e., eggs, larvae and pupae) require an aquatic environment, and the adult mosquito an aerial and terrestrial one. The four successive stages of development in the life cycle of the anophelines and culicines are briefly described below and illustrated in Fig. I-1.

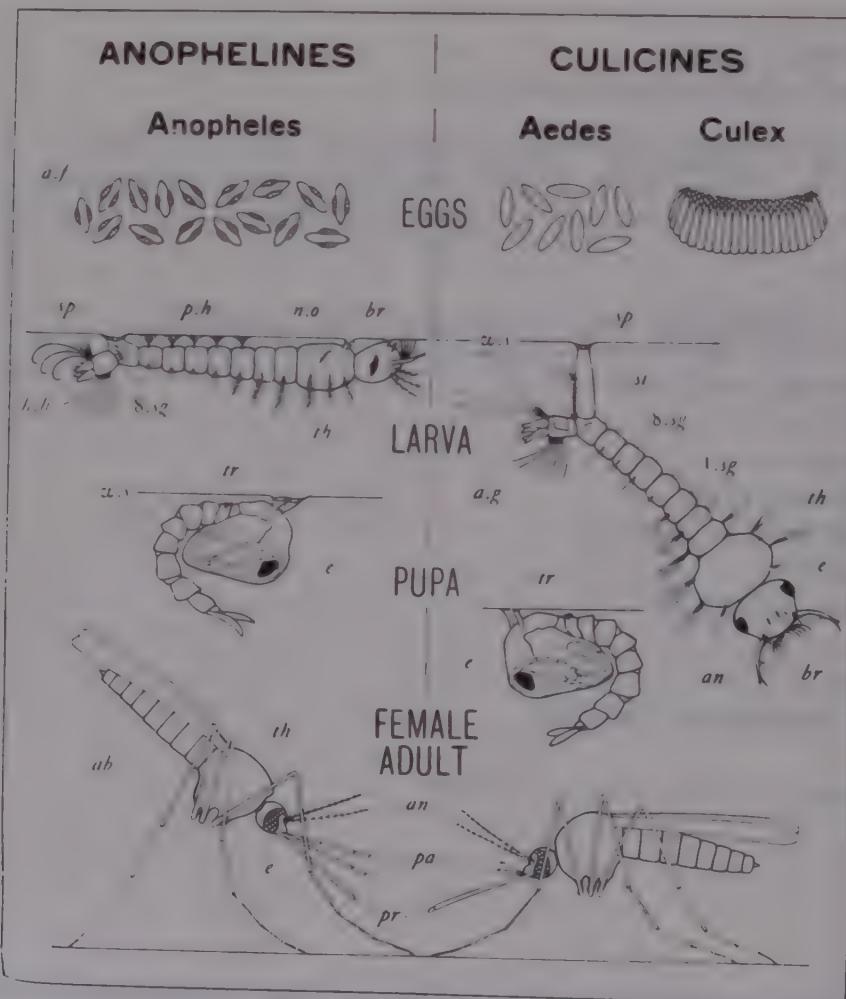


Fig. I.1. Chief distinguishing features of Anophelines and Culicines. (a.f., air floats; a.g., anal gills; ab., abdomen; an., antenna; br., mouth brush; e., eye; h.h., hooked (or grapnel) hairs; n.o., notched organ; pa., maxillary palp; p.h., palmate (or float) hairs; pr., proboscis; 1 sg., 1st abdominal segment; 8 sg., 8th abdominal segment; si., siphon; sp., spiracles; th., thorax; tr., respiratory trumpets; w.s., water surface).

(From: Marshall, J.F., The British Mosquitoes, 1938 (reprinted 1966, Johnson Reprint Corp.), Fig. 13, p. 13).

Egg

Anophelines lay their eggs separately over the surface of water, each egg having lateral air floats to keep it afloat. Culicines of the genus Culex and Mansonia lay their eggs on the water, in a boat-shaped mass referred to as an egg raft; whereas those of the genus Aedes are laid separately, often in dry hollows or containers which become flooded after rain. These "dry-laid" eggs are able to retain their viability without water for very long periods.

Larva

Eggs of mosquitos generally hatch after two or three days in contact with water. The larva is about 1.5 mm long when newly hatched and about 10mm long when fully grown. During growth the larva casts its skin four times, the stages between successive moults being known as instars. The larva of a mosquito is made up of head, thorax and abdomen — the last being composed of nine distinct segments. A mosquito larva breathes through two orifices, called spiracles; those of the anopheline being situated on the eighth abdominal segment so that, in order to breathe, the larva rests in a horizontal position at the surface of the water. In culicine larvae, the spiracles are situated at the end of a tubular organ, called the siphon, which extends from the eighth abdominal segment. Since the spiracles must lie in the plane of the water surface, the culicine larva must hang down from the water surface by the tip of its siphon in order to breathe. An exception is the genus Mansonia, in which the siphon is highly modified for piercing and adhering to stems of aquatic plants from which air is drawn for breathing purposes.

Pupa

The pupa is a non-feeding stage, of several days duration, providing for the morphological and physiological changes required for transformation of the larva to the adult.

The general appearance of the pupa is of a comma with an exaggerated "dot" and small "tail". The "dot" is occupied by the head and thorax while the "tail" encases the abdomen which terminates in a pair of paddles. The pupa is mobile and able to dive rapidly when disturbed. When quiescent, the pupa rests at the surface of the water, suspended by a large air cavity within its body. Breathing is carried out, at the surface of the water, by a pair of respiratory trumpets extending from the thoracic area. In general, culicine pupae can be distinguished from anopheline pupae by their considerably longer respiratory trumpets.

Adult

The adult mosquito emerges, thorax first, from the pupal skin, by swallowing air to increase the internal pressure within the pupal skin and then to enable the mosquito to extend its soft limbs into the adult form. After emergence, the adult mosquito rests for a few minutes on the discarded pupal skin for its wings to expand and harden prior to flight. The proboscis takes longer to harden and is too soft, during the first day after emergence, for the female to take a blood meal. The adults of both sexes feed on plant juices but only the female feeds on blood. Egg development is dependent on a blood meal for almost all anophelines and most culicines. In some species the first batch of eggs can be laid without a blood meal (autogeny). While there are precise morphological differences between anophelines and culicines, which are outside the scope of this manual, the former may generally be distinguished from the latter by the appearance of the wings. With the exception of species of the subgenus Anopheles, the anopheline wing is generally patterned with dark and pale areas whereas the culicine wing is unpatterned and has a uniformly plain appearance. Another visual distinction is that, at rest, the body of an anopheline mosquito forms an angle nearly vertical with the surface while that of a culicine mosquito lies almost parallel to the surface as shown in Fig. I-1.

1.2 Mosquito bionomics

Bionomics deals with the relationship between a given species and its environment. An understanding of mosquito bionomics is therefore of key importance in the epidemiology of mosquito-borne diseases and in planning methods of mosquito control. Climatic factors play an important part in species distribution, behaviour, survival and vectorial status. Water is an essential component of the mosquito environment and whether it is running, standing, clean or polluted, sweet or brackish, shaded or sunlit, frequently determines which species of mosquito breeds in it. The environments of the immature stages and adult mosquito are interdependent since the adult mosquito must have access to water for egg laying. The adult mosquito environment is, however, largely aerial and terrestrial, the former environment being necessary for mating and dispersal and the latter providing habitats for feeding, resting and completion of the cycle of ovarian development from blood meal to egg laying. The environments of the immature stages of the adult mosquito are considered in more detail below.

1.2.1 The environment of the immature stages of the mosquito

The environment of the immature stages of the mosquito is aquatic, with its mobile stages (i.e., larva and pupa) dependent on atmospheric air for breathing and therefore typically spending much of their lives suspended from the surface film of the aquatic environment.

There is an optimal range of water temperatures for growth of the immature stages of the mosquito. This range is lower for species living in temperate than in tropical zones and varies somewhat between different species living in the same geographical zone: thus temperature is one of the factors that limits the geographical distribution of a species. Within these optimal ranges, however, there is a largely direct relationship between temperature and growth. For example, mosquitos breeding in the tropical zone, in water at 23°-27°C, usually complete their aquatic growth within two weeks. Moderately frequent rainfall usually increases the opportunities for prolific breeding, but repeated and heavy rainfall causes severe flooding resulting in a temporary flushing out of breeding places and reduction in mosquito population. The depth to which light penetrates the water in which the mosquito is breeding is generally not an important factor since the immature stages live largely at the water surface, but the extent to which the breeding place is shaded or exposed to sun determines which species of mosquito inhabit a particular water body. Hedges, planted to give shade over breeding places, or clearing of forests to allow sun to penetrate have been successfully used for environmental control of several malaria vectors (Anopheles minimus and An. balabacensis). Unless islands of vegetation are present to provide local breeding sites, mosquito larvae are not found on open surfaces of large bodies of deep fresh water (e.g., lakes, ponds, rivers or reservoirs) but are confined to their sheltered shallow edges. The immature stages of some species (An. gambiae s.l.) are found throughout the entire surface of swamps and of shallow temporary rainwater pools. Some species (An. funestus) breed in clear fresh water with vertical vegetation whereas others are adapted to breeding in brackish water (An. sundaicus) or highly polluted water (Culex quinquefasciatus = Cx. pipiens fatigans). The aquatic environment of some species is associated with particular plants. For example, Mansonia larvae are linked with the presence of fresh water lettuce (Pistia) and Aedes simpsoni with axillary breeding in banana plants. Other species (Ae. aegypti, Eretmapodites chrysogaster) breed in great numbers in small containers such as old tins, tyres and coconut husks.

Thus while mosquitos, as a group, are found breeding in an almost infinite variety of sizes and types of water body, each species is generally associated with certain types of breeding places. In some species, however, breeding is restricted to a narrow range of habitats while others breed readily in a wide range of water-types. The classification given in Annex 1 attempts to identify the major and most common mosquito vectors, their biology and breeding habitats, and to indicate, for each type, the most suitable environmental management measures for control.

1.2.2 The environment and habits of the adult mosquito

Mating

Mating usually occurs within 24-48 hours after emergence. In some species the males form a swarm, frequently located over contrasting or sharply defined points, e.g., the top of a tree, stake or rock, or over the corner of a building. Swarming usually occurs at dawn or in the evening, but may be seen in shaded areas in the middle of the day. Females entering the swarm are seized and the pair drops out of the swarm. After insemination, the spermatozoa are stored in the female mosquito, in an organ called the spermatheca, and drawn on for fertilization of all the eggs produced throughout the remainder of its life (monogamy).

Dispersal

The adult mosquito of most species does not fly great distances and the male is a much weaker flyer than the female. Thus the presence of a large number of adult male mosquitos indicates that breeding places of that particular species are close by. In normal atmospheric circumstances, most individual mosquitos of tropical species apparently fly within a range of 1-3 km, although there are records of a few species or occasional individual mosquitos travelling much further. Certain temperate-zone species travel 4-5 km and there are records of those that travelled up to 10 km. Dispersal is largely downwind and strong winds can carry mosquitos very much greater distances than normal. For example, there is a report of Anopheles pharoensis, in Egypt, being windborne, up to 280 km from the nearest breeding places.^a Dispersal of mosquitos through human agency has occurred since the earliest times but with the increasing number of vehicles (boats, buses, trains and aircraft), the threat of passive dispersion of vector species is much greater today, and effective countermeasures such as vehicle disinfection are required.

Biting habits

Many of the habits of adult mosquitos are linked to their being both cold-blooded and physiologically ill-fitted to withstand very dry environments. Flight, host seeking, and feeding generally take place in a warm humid environment. Species that are associated with open terrain and sunlit habitats fly and feed between the hours of dusk and dawn when the air is more humid. Many of these species have a peak of biting activity in the latter half of the night when relative humidities are at their highest. For example, in An. gambiae s.l. and An. funestus, the principal vectors of malaria in Africa, the peak of biting occurs about an hour before dawn. Many species associated with dense vegetational habitats such as forests or plantations, where daytime humidities are generally higher than in open terrain, fly and feed during daylight hours. Their peaks of biting activity vary widely between different species and may occur in daylight hours (Aedes simpsoni) or shortly after dusk (Ae. africanus). Mosquitos which feed inside houses are described as endophagic and those that feed outdoors as exophagic. The exact feeding pattern of mosquitos indoors varies with different species and circumstances but usually mosquitos enter houses to feed in the early hours of the night.

Host preference

The environment of the adult female mosquito includes a host. If the preferred host is man, the mosquito is referred to as anthropophilic; if animal, as zoophilic; and if there is no fixed preference, as an indiscriminate biter. In the absence of the preferred host, some species (e.g., An. gambiae s.l.) are facultative feeders and will feed readily on

^a Garrett-Jones, C. The possibility of active long-distance migrations by Anopheles pharoensis Theobald. Bulletin of the World Health Organization, 27: 299-302 (1962).

another host. In Europe, changes in agricultural practices leading to improved rural housing and the construction of separate buildings for housing cattle and pigs have diverted malaria vectors away from man and led them to feed on domestic animals.^a, ^b

Resting habits

Species that enter houses for feeding at night and for resting in the daytime are described as endophagic and endophilic, as compared with exophagic and exophilic mosquitos which feed and rest outdoors. The siting, design and construction of houses can greatly influence the extent to which houses can be entered and used as resting places by mosquitos, and constitute an important aspect of environmental management. For example, governments and communities of developing countries tend to build "low-cost housing" away from swamps and more individuals have houses with well-fitting doors and screened windows. The pattern of mosquito resting inside houses is also changing with the addition of ceilings to bedrooms and the wider use of cupboards, thereby removing many adventitious resting places on clothes (and other articles) hanging from nails and lengths of string fixed along walls. The widespread use of corrugated iron sheets instead of grass for roofing houses in rural areas, especially in Africa, has forced mosquitos to seek indoors suitable resting places because the roof-surfaces are unbearably hot in the daytime.

In areas where species are largely endophilic, there is nevertheless an outdoor resting component of males, recently emerged females, gravid females and females that have recently laid eggs. Where the population is largely exophilic, a great number of recently blood-fed mosquitos are found among the outdoor resting population. The vegetational habitats of exophilic mosquitos vary greatly according to species and geographical area and they range from sparse xerophytes to tropical rain forest ecotypes. The principal hosts may be cattle, wild mammals, or birds with man playing the role of an accidental host. Outdoor resting mosquitos are usually widely distributed over large areas and their environmental management is generally more difficult than for endophilic mosquitos whose females are concentrated during part of their lives into discreet units, i.e., houses or other man-made shelters. Outdoor resting places of mosquitos are generally sheltered, shaded, and humid and include earth banks, crevices in the ground, caves, spaces under bridges, dense vegetation and the bases of tree trunks. While some species use a variety of resting places, others prefer specific sites. In tropical countries it is common practice to clear vegetation around houses to reduce the nuisance of mosquitos biting people outdoors. Plants (such as plantain and bananas) that provide breeding and resting sites for Aedes mosquitos are prohibited within some towns. In the wet season the growth of vegetation leads to increased outdoor resting in some species such as Anopheles gambiae s.l. The collection of outdoor resting mosquitos is often much easier in the dry season, however, because of their concentration in the relatively few remaining natural resting sites. In some areas where outdoor resting sites are greatly reduced in the dry season, houses are extensively used seasonally as resting places by mosquitos that have fed outdoors on cattle. It can thus be appreciated that the extent of endophily, endophagy, exophily and exophagy varies within the same species, according to environmental conditions.

Gonotrophic cycle

Mosquitos enter houses through open windows, doors, eaves gaps, and gaps in walls. After entering, some species rest inside the house for a period of 2-3 hours before feeding indoors on man and then, gorged with the blood meal, rest indoors for 24-48 hours until the blood has been digested and the ovaries contain mature eggs, i.e., they are gravid. The gravid mosquito typically leaves the house at dusk in search of a suitable aquatic site for

^a Roubaud, E. Les conditions de nutrition des Anopheles en France. A. maculipennis et le rôle du bétail dans la prophylaxie du paludisme. Annales de l'Institut Pasteur, 34: 181 (1920).

^b Wesenberg-Lund, C. Contributions to the biology of the Danish Culicidae. Kongelige Danske videnskabernes selskabs skrifter, 7: 1-110 (1921).

egg laying. Mosquitos that enter but are unsuccessful in obtaining a blood meal generally leave the following dawn.

Seasonal prevalence

In certain areas, mosquitos are seasonally exposed to a hostile environment created by extremes of climate. In temperate zones, winter temperatures are survived by some form of hibernation. In the colder parts of the temperate zone, hibernation in Aedes spp. is in the egg stage and there may be only one generation a year. In the less cold parts of the temperate zone, most culicines spend the midwinter months in the larval stage. The female adults of some, e.g., Culex pipiens, hibernate in sheltered places such as cellars or out-buildings, surviving on body fat. Adults of other species such as Anopheles atroparvus hibernate partially, taking an occasional blood meal off man or domestic animal, indoors, during a warm spell, but in these circumstances ovarian development does not follow after the blood meal. This physiological condition is described as gonotrophic dissociation. Some tropical species (An. gambiae s.l.) are able to survive in hot, dry and apparently waterless areas in parts of Africa towards the end of the dry season, but the means by which they do so are not yet known.

Extrinsic incubation period and mosquito longevity

Since the mosquito is cold-blooded, the climate in which it lives greatly affects its capability for disease transmission by influencing the rate of development of the parasite within the vector and the longevity of the mosquito.

Malarial and filarial parasites undergo a developmental cycle within the mosquito host during which the former, but not the latter, parasites multiply. Viruses multiply within the mosquito host but do not appear to undergo any cyclical change. For all three groups there is a period between the host mosquito's first infectious blood meal and its first feed transmitting the infection. This interval is known as the extrinsic incubation period and varies in length in response to the temperature of the host mosquito's environment. For example, development of the malaria parasites, Plasmodium falciparum and P. vivax, is indefinitely retarded at 19°C and 15°C respectively and below; and in P. falciparum it is completed in 10 days at 30°C and in 27 days at 20°C (Macdonald 1957)^a. Rao and Iyengar^b found that mean temperatures below 24°C and 34°C inhibited growth of the filarial parasite Wuchereria bancrofti in Culex quinquefasciatus Say (=Cx. p. fatigans Wiedemann) and Khalil et al.^c found that the filarial larvae matured in 20 days at 23-24°C and in 14 days at 29-31°C. Further details on the extrinsic incubation period of W. bancrofti are given by Sasa.^d Davis^e found that the extrinsic incubation period of the African Asibi strain of yellow fever virus in Aedes aegypti was 4 days at 37°C, and 18 days at 21°C. The mosquitos were not infective after a period of 30 days at 18°C.

^a Macdonald, G. The epidemiology and control of malaria, London, Oxford University Press, 1957.

^b Rao, S.S. & Iyengar, M.O.T. Studies on incidence of season on development of Filaria bancrofti in Culex fatigans. Indian journal of medical research, 17: 759-768 (1930).

^c Khalil, M. et al. On the transmission of filariasis bancrofti in Egypt. Journal of the Egyptian Medical Association, 15: 317-322 (1932).

^d Sasa, M. Human filariasis. A global survey of epidemiology and control, Baltimore, University Park Press, 1976.

^e Davis, N.C. The effect of various temperatures in modifying the extrinsic incubation period of yellow fever virus in Aedes aegypti. American journal of hygiene, 16: 163-176 (1932).

While some species of mosquito live longer than others, temperature and humidity affect their survival. Except at extremely high or low humidities, when mosquitos are unable to regulate their water loss, longevity is in general greater at the higher ranges of humidity and lower ranges of temperature. Anopheles culicifacies was found to survive about 10 days at a 60-65% relative humidity and at 30-35°C, compared with 30 days at 80-90% relative humidity and 27-30°C.^a

Resistance to insecticides

During the last 35 years, control of mosquitos and other insects of public health importance has been largely achieved by means of synthetic chemical insecticides. Their use on a vast and increasing scale has led to the widespread development of insecticide resistance which has been defined as "the development of an ability in a strain of insects to tolerate doses of toxicants which would prove lethal to the majority of individuals in a normal population of the same species".^b The number of insecticide-resistant arthropods of public health importance has risen from 2 in 1946 to 155 in 1980, and insecticide-resistant mosquitos from 7 in 1957 to 98 in 1980. Resistance has appeared to chlorinated hydrocarbon, organophosphate and carbamate insecticides. As there are few alternative groups of chemical insecticides to fall back on, it has become urgent to develop alternative means of mosquito control.

Insecticide resistance is inherited and is induced through selection of individual insects that survive dosages of insecticides which kill the susceptible individuals. The mechanism of inheritance varies with different insect groups and different insecticides. It can be of a simple mendelian character attributable to a single gene allele, or of a complex nature involving oligogens or multiple-gene interaction. The physiological basis of resistance also varies with species and insecticides, and may arise through enhanced metabolism of the insecticide, reduced penetration of the insecticide into the insect, or reduced nerve sensitivity.

2. Major mosquito-borne diseases and their epidemiology^c

2.1 Malaria

Malaria is responsible for high infant mortality rates among many populations in the tropical and subtropical climates of the world. Also of great concern is its chronic effect of debility and general impairment of wellbeing that obviously hinders the economic and social progress of communities where malaria is widespread.

Malaria parasites are protozoa of the genus Plasmodium and there are four main species, Plasmodium falciparum (malignant tertian malaria), P. vivax (benign tertian), P. malariae (quartan) and P. ovale, the latter species being relatively uncommon. After receiving an infective bite, there is an incubation period in the patient which varies from 10-40 days depending on the species of Plasmodium. Towards the end of the incubation period the patient may suffer headaches, limb-pains, backache, slight nausea or even vomiting. The incubation period terminates with the onset of the disease which is characterized by a paroxysm which develops in three well-defined stages, the cold stage or chill, the hot or fever stage and the sweating stage. The paroxysm is caused by massive destruction of the red corpuscles and release from them of toxins into the blood stream. If untreated, the paroxysms develop a

^a Russell, P.F. & Rao, T.R. Observations on longevity of Anopheles culicifacies imagines. American journal of tropical medicine, 22: 517-533 (1942).

^b WHO Technical Report Series, No. 125, 1957 (Insecticides: seventh report of the Expert Committee).

^c See also Annex 1.

periodicity, occurring every three days in P. falciparum, P. vivax and P. ovale, and every four days in P. malariae. Malignant tertian is the most serious form of human malaria since it is more likely than the other forms to give rise to fatal complications. However, P. falciparum does not survive in the human body longer than two years whereas P. malariae is capable of surviving undetected for more than twenty years and then suddenly manifesting itself.

After invading the red corpuscles of the blood, the malaria parasites develop into numerous noninfective trophozoites and a smaller number of infective male and female gametocytes. When a mosquito vector bites an infected person and ingests blood containing male and female gametocytes, a complex cycle of development and multiplication of the malaria parasite takes place, at the end of which the salivary glands of the mosquito contain infective sporozoites ready for injection into another person at the next bite.

The cycle of transmission of malaria is exclusively between man and vector mosquito, with man acting as sole intermediate host and reservoir of the parasite and the mosquito as the definitive host. The epidemiology of the disease depends upon a great many factors including the habits of man and of the vector mosquito, the species of parasite and the environment. The rate of transmission is influenced by the efficiency of the vector (i.e., the ease with which it acquires and develops an infection), the size of the reservoir of infection (i.e., number of infected individuals), and the "vectorial capacity" which is a function of the density of the vector, the rate at which it feeds on man, the length of survival of the infected vector mosquitos, and the duration of the incubation period in the vector.

Table 1.1 (Annex 1) presents a list of the Anopheles mosquitos most commonly incriminated in malaria transmission and their chief preferences in breeding habitats; they are grouped according to geographical distribution.

Table 1.2 (Annex 1) presents an alphabetical list of Anopheles species that are important in malaria transmission, with a summary of information on the adult mosquito habits and on larval habitats.

2.2 Filariasis

Mosquito-borne filariasis in man includes a group of diseases caused by filarial nematodes. The immature and adult worms invade the lymphatic system. Microfilariae are found in the blood and there may be eosinophilia. The number and location of the parasites (and whether they are alive or dead) influence the clinical manifestations of the disease. Repeated infections may lead to illness and incapacity for work arising from filarial fever, inflammation and enlargement of the lymph nodes and vessels (adenolymphangitis), incompetence of the lymphatic valves, obstruction of the lymph-flow and varicose dilation of the lymphatic vessels. In the inguinal and testicular regions this frequently leads to hydrocele. Long exposure to repeated infections, usually over several years, can lead to extensive lymphatic obstruction and a massive increase in lymphatic and fibrous tissue in the limbs, thereby giving rise ultimately to the characteristic deformity known as "elephantiasis".

The species of filarial worms involved are Wuchereria bancrofti, Brugia malayi and B. timori. W. bancrofti has an extensive geographical distribution and is found in nearly all tropical countries. Its transmission cycle is man-mosquito-man (i.e., non-zootic). B. malayi is known only from south and east Asia. Its nocturnally subperiodic form, found in the jungle swamps of West Malaysia, is zootic and the transmission cycle involves other vertebrates such as monkeys, domestic and wild cats, civets and pangolins in forested areas. B. timori is a distinct, apparently non-zootic species, found on the Lesser Sunda Islands in Eastern Indonesia.

In the developmental cycle of W. bancrofti, man is the definitive host in which the adult female filarial worm, after copulation with the male worm in the human body, gives birth to numerous microfilariae which enter the peripheral circulation. When taken up in a blood meal by the mosquito intermediate host, the microfilariae develop primarily in the thoracic muscular tissues of the mosquito until they reach the infective stage, and then they enter the

proboscis of the vector. When the mosquito bites man, the infective stage larvae are deposited from the proboscis onto the skin and penetrate the wound inflicted by the mosquito. After penetration, the male and female filariae enter and grow in the lymphatics. The developmental cycles of the Brugia spp. are similar except that other vertebrates, as well as man, may act as definitive hosts.

The microfilariae in the peripheral blood vessels exhibit nocturnal periodicity in W. bancrofti infections throughout most of their geographical distribution, with high densities appearing in the bloodstream at night and very low densities or none in the daytime. In some places the microfilarial periodicity in W. bancrofti infections is less marked and is known as subperiodic. In the South Pacific islands it is diurnally subperiodic. In parts of Thailand it is nocturnally subperiodic. Similarly, B. malayi is nocturnally periodic in most parts of tropical Asia, but the jungle form, found in the swampy areas of West Malaysia, is nocturnally subperiodic. The microfilariae of B. timori are nocturnally periodic. The phenomenon of microfilarial periodicity is not fully understood but appears to be linked with the biting-cycle of the vector mosquitos.

The epidemiology of the disease is influenced by topography, climate, social conditions, and degree of exposure to infective mosquitos. The incidence is highest in coastal and flat areas in tropical latitudes but low in mountainous areas. Advanced levels of filarial disease are generally found only in areas with very high densities of the vector mosquito where the inhabitants have had long exposure to repeated infections. Some 59 species of mosquito have been reported as natural vectors of bancroftian filariasis, the most important of which are indicated in Tables 1.3 and 1.4 (see Annex 1). Culex quinquefasciatus (= Cx p. fatigans) is the principal vector in urban situations. It breeds in polluted waters such as cesspits, stagnant water in ditches and drains, and in tanks, barrels and all sorts of containers. It is strongly anthropophilic and bites man indoors and outdoors. This species, and its association with bancroftian filariasis, is presenting a mounting problem in many urban situations where installations such as standpipes, latrines and drains are not properly maintained. Transmission of brugian filariasis occurs in all combinations from animal to animal or man, from man to man or animal. The major vectors are the swamp-breeding species of Mansonia. In East Indonesia, B. timori is transmitted by Anopheles barbirostris.

Filariasis vector control is usually supplementary to chemotherapeutic control with diethylcarbamazine nitrate. It is carried out on a limited scale by house spraying with residual contact insecticides and by means of ultra-low-volume formulations of insecticides applied indoors and outdoors. The widespread resistance of adult Cx quinquefasciatus to organochlorine and other synthetic insecticides does, however, stress the need to look at other means of control, particularly environmental ones.

Table 1.3 (see Annex 1) gives the principal mosquito-borne filarial parasites of man, their geographical distribution and preferred types of environment, notes on the epidemiology of the disease, and the mosquitos most commonly involved in its transmission. Table 1.4 presents a list of the important mosquito vectors in alphabetical order, with a summary of information on the adult mosquito's habits and on larval habitats.

2.3 Yellow fever

Yellow fever is an acute, often fatal, disease caused by an arbovirus. The disease is characterized by severe headaches, aches in the bones, and fever followed by a deep jaundice, internal haemorrhages and vomiting.

Like most viral diseases transmitted by mosquitos, yellow fever has an animal reservoir. Jungle monkeys are the normal reservoirs of the virus. In South and Central America the Haemagogus mosquito which occasionally bites man, is a major monkey-to-monkey vector. However, in Africa, monkey-to-monkey transmission is maintained by the forest mosquito, Aedes africanus, and from monkey to man typically by Ae. simpsoni which breeds profusely in plantain and banana plantations at the periphery of the forest, in the vicinity of man. Subsequent transmission follows a man-Aedes-man cycle in which Ae. aegypti can play a major role in an urban environment. As Ae. aegypti breeds near human habitations in plant axils, potholes and artificial

containers of all sorts and sizes, the disease (which is normally confined to forest and rural areas) can become an urban health problem and even burst into epidemic proportions.

The development of effective vaccines and their massive application, together with the successful results of mosquito control programmes in the recent past, have reduced the disease to a fraction of its overall global importance half a century ago. The threat of a sudden epidemic remains ever present, however, and measures have to be taken to cope with this eventuality. Programmes of chemical control of Aedes mosquitos have somewhat suffered from the difficulties encountered with other vector mosquitos; there is thus a corresponding need to instigate alternative methods of control.

2.4 Dengue haemorrhagic fever

Dengue haemorrhagic fever is an acute febrile disease of low fatality, characterized by high fever, intense muscular and joint pains and prolonged incapacitation. The causative agent is a virus related to that of yellow fever.

No reservoir other than man is known. The primary vector is the cosmopolitan Aedes aegypti but other Aedes (such as Ae. albopictus and some members of the Ae. scutellaris group) have been incriminated. The vector can acquire the infection from an infected person up to 3 days after appearance of the initial symptoms, and the extrinsic incubation period may be as short as 8 days.

Explosive epidemics of dengue haemorrhagic fever have occurred in urban situations in which Ae. aegypti has been the vector. The disease has been countered by chemical insecticides but there is a need to develop alternative methods of control including environmental ones.

2.5 Encephalitis and other viral diseases

Other mosquito-borne viruses include the neurotropic viruses that attack the central nervous system of their hosts causing encephalitis. There are three principal encephalitis viruses in the USA, Western equine, St. Louis and Eastern equine. Japanese B virus is prevalent in the Far East and Murray Valley virus in Australia. Rift Valley fever is widespread in Africa. The encephalitis viruses give rise to inflammatory diseases of the brain and spinal cord with signs and symptoms which are similar but vary in severity and rate of progress: these include high fever, stupor, disorientation, coma, tremors and spastic paralysis. Japanese B virus may give rise to a high case fatality rate, higher than malaria.

The three encephalitis viruses of the USA are primarily parasites of birds with Culex tarsalis being an important vector of Western equine and St. Louis encephalitis. Eastern equine is transmitted from bird to bird by Culiseta melanura but Aedes sollicitans plays a significant role in carrying the infection to horses and man. In the Far East, Japanese B virus is primarily a parasite of mammals, and pigs can play an important role in the epidemiology of the disease. Extensive human outbreaks, transmitted by Cx tritaeniorhyncus and Cx quinquefasciatus (= Cx p. fatigans), can occur. Murray Valley virus is enzootic in many mammals and birds in north-eastern Australia and is transmitted by Cx annulirostris. Eighteen species of mosquitos have been implicated in the transmission of Rift Valley fever and, in a recent major epizootic of this disease in Egypt, Cx pipiens was detected as the major vector.

There are many other viral diseases transmitted by mosquitos and Table 1.5 (see Annex 1) presents a list of the more important ones, their geographical distribution, summary notes on their epidemiology, and the most common vector species involved in the transmission. Table 1.6 (see Annex 1) presents a list of the important mosquito vectors of arboviral diseases in alphabetical order with a summary of information on the habits and larval habitats of the adult mosquitos.

3. The available methods of mosquito control

3.1 Introduction

The prevention and control of a number of important vector-transmitted, communicable diseases of man rely heavily on measures for the control of the vector populations. Usually such measures represent the most effective and often most feasible and economical means of disease prevention and control. In the case of certain diseases (such as trypanosomiasis, for which effective and safe drugs are still to be developed), vector control is at present practically the only safe and effective method of large-scale control.

In mosquito-borne diseases, vector control may be directed to controlling the breeding of vectors and thus reducing the vector population. This may be achieved by applying chemical larvicides, by introducing biological agents in the breeding habitats, or by implementing environmental management works and operations.

Vector control may also be directed against adult mosquitos. The general objective is similarly an adequate reduction in the mosquito vector population. However, in certain operations (such as indoor residual or space spraying) the control measures may be more selective and directed against only that portion of the mosquito population that enters, feeds on man and rests indoors. In this case, mosquito longevity is reduced and the mosquitos die before they can become infective and transmit the disease to man.

The methods of mosquito control may be used for (a) preventing the occurrence of diseases, (b) suppressing epidemics, or (c) controlling already existing endemic mosquito-borne diseases. They are usually applied in combination, in a balanced mix of various methods, integrated to suit local conditions and needs and resources and to ensure the maximum cost-effectiveness and benefit. For disease prevention and control, the methods of mosquito control form a segment of the general integrated control strategy where antipathogenic measures, e.g., drugs, vaccination, etc., are also included.

The available methods of mosquito control are usually classified into chemical, biological and environmental, depending on whether the control of vectors is attempted through the use of chemicals or biological agents, or by management of the environment.

3.2 Chemical methods

The use of insecticides for the control of malaria and other vector-borne diseases acquired great impetus with the advent of DDT and other organochlorine compounds in the late 1940s. Their use in public health increased in extent and intensity with the worldwide programme of malaria eradication which was initiated in 1956/57. The residual insecticidal effect of some of these chemicals made it possible to sustain an attack on the malaria vectors by means of the periodic indoor spraying of houses (see section 3.2.1 below).

The development of mosquito resistance to some residual insecticides, and the elusive behaviour of certain mosquito vectors have diminished the effectiveness of residual spraying and hence the extent of its application. Faced with this problem and in line with the universal acceptance of the principles and advantages of an integrated approach, planners and operators of vector control programmes have directed their attention to other methods of mosquito control such as larvicing, the space application of pesticides using ultra-low-volume (ULV) techniques or thermal fogging, and the reintroduction of environmental management and biological control measures to supplement residual spraying.

In the control of certain mosquito-borne diseases such as dengue haemorrhagic fever and the encephalitides, reliance is at present placed mainly on aerosol application of pesticides (ULV, fog, mist, etc.). For others, e.g., urban yellow fever, larvicing also has a prominent place. In antimalaria programmes, there is still heavy reliance on residual insecticide applications indoors, while larvicing is increasingly being used, particularly in urban environments. The introduction of other methods of mosquito control has been slow.

The advantages of chemical methods of mosquito control are that they can be organized within a short period of time, are effective, and can produce quick results at reasonably low cost. Hence they are extremely effective in dealing with emergencies, disease outbreaks and the protection of specific population groups, e.g., labour force, migrants, new settlers, etc. They also have a special place in mosquito-borne disease control programmes, particularly at the outset to reduce endemicity and to allow other control measures to develop and play an effective role in the integrated strategy.

It should be emphasized that the application of chemicals for mosquito control should be planned with care and based on adequate knowledge of vector bionomics and disease epidemiology, as most chemicals are toxic to man and are costly. More importantly, only a limited number of safe and effective pesticides are available for public health use; this is especially so for those with long residual effect. The long-term repeated application of pesticides may induce vector resistance, particularly if they are also used in agriculture; if used outdoors, there will also be undesirable environmental implications. Therefore, the use of chemicals should be combined with the progressive use of non-chemical methods.

In the following sections chemical control methods are briefly described.

3.2.1 Residual spraying

Residual spraying is still the most effective and feasible method for the chemical control of mosquito vectors of malaria. For the control of other mosquito-borne diseases, the use of this method is rather limited.

The technique consists in spraying insecticides that have a persistent effect on all surfaces where mosquitos are likely to rest — the inside walls and ceilings of houses, barns, storerooms, stables, etc., and the undersides of roof eaves and other structural projections, beds, tables and other furniture. The persistent or residual effect varies with the kind of insecticide, its formulation, the dosage applied, the type of surfaces sprayed, and the climatic conditions. The duration of the residual effect usually varies from a few weeks to over a year. The attack is mainly directed to those endophilic mosquito vectors which frequent human habitations, and bite and rest indoors. These vectors, while resting on the sprayed surfaces, come into contact with the insecticide and should die before they become infective and able to transmit the disease.

For the eradication of malaria, which implies the interruption of transmission for a sufficient number of years, the spraying coverage of the structures (mentioned above) should aim at being total, complete and sufficient. Actual practice in many situations has shown that these requirements are difficult to fulfil, but nevertheless malaria transmission has been successfully interrupted in most situations. Where such transmission has not been interrupted, it was considerably reduced and the addition of other measures helped to further reduce or even interrupt it.

Residual insecticides are usually applied by means of a hand compression sprayer. Up to the present, the following three groups of pesticides have been used in indoor spraying in antimalaria programmes.

Organochlorine compounds

The most common are DDT, dieldrin, and HCH; they are applied in solution, emulsion or suspension as a water-dispersible powder. Water-dispersible powders have proved to be the most convenient for field use as they may be mixed with water in the rural areas immediately before application. They have also proved to have a longer residual effect, especially on porous surfaces such as mud walls.

DDT was the insecticide most widely used in antimalaria programmes until the early 1970s.

Dieldrin is a very effective insecticide but is more expensive than DDT, and its higher toxicity to man has precluded its use in public health programmes.

HCH is less toxic than dieldrin, its residual effect is shorter, and it has an airborne insecticidal effect. The compound has not been used widely in large-scale antimalaria programmes mainly because dieldrin was preferred and, once a resistance to dieldrin was produced, there was a cross resistance to HCH as well.

Organophosphorus compounds

The development of vector resistance to organochlorine compounds led to the use of the organophosphorus and carbamate groups as substitutes. They are more expensive, are usually more toxic to man, and often have a shorter residual effect than the organochlorine compounds used in public health programmes. These three factors contribute to higher operational costs, more frequent cycles of application, greater bulk to be transported, and more costly safety measures and equipment.

Among this group of compounds, malathion is the insecticide most widely used in anti-malaria programmes. Vector resistance to malathion has been reported in a number of countries.

Fenitrothion is another organophosphorus compound of longer residual effect than malathion but of higher cost and toxicity. Its use in residual spraying is increasing.

Carbamate compounds

Propoxur is a carbamate compound that is highly toxic to mosquitos and has an airborne effect. It has been used since 1979 in large-scale antimalaria programmes in Central America and since 1978 in Iran. However, its high cost limits its use.

3.2.2 Larviciding

The earliest chemical control of mosquitos was directed against the larval stage. By the end of the last century the first larviciding technique was developed. Crude kerosene and distilled petroleum oils were applied to mosquito breeding sites. The arsenical, Paris Green, is another old larvicide still used on a very limited scale in some antimalaria programmes. Both Paris Green and oils were largely replaced by newer and more effective compounds after the Second World War.

Temephos is a commonly used larvicide; its low mammalian and fish toxicity, its lower cost compared to oils, and its efficacy at lower dosages are factors in favour of its use in many mosquito control programmes.

Fenthion and chlorpyriphos are also used as larvicides, particularly against culicines breeding in polluted waters; their toxicity is higher and they must therefore be used with care and caution.

Some of the new larvicides are short-lived and they break down in water within a few days. Liquid larvicides are applied on water by various types of ground and aerial spraying equipment; granules and dusts may be applied by hand or by different types of dispersal equipment. Generally, compounds in emulsion-concentrate formulations have proved to be most convenient for larviciding. The daily supply of concentrates can be easily carried in a small bottle and can be diluted with water from the breeding place and applied. Compounds in granules or dusts involve the transport of a considerable weight and so their use is limited to situations where they are absolutely necessary or where transport is easy.

3.2.3 Space spray application

The attack on the adult mosquito by applying atomized insecticide droplets in indoor spaces where mosquitos may be flying or resting is not new. The "Flit" gun has been a household tool for mosquito control for over half a century. The more recent household type of aerosol dispenser is a great improvement. The mist produced contains minute droplets that remain airborne for periods long enough to kill flying mosquitos. Pyrethrum and pyrethroid compounds, dichlorovos, and similar insecticides are widely used in aerosols.

Techniques have been developed for the application of insecticides to open spaces. The principle is the same as for indoor application — namely, the production of a mist or fog of sufficient insecticidal efficacy to destroy adult mosquitos in their resting and flying areas. In practice, these techniques usually require sophisticated equipment, skilled manpower, and a high degree of organization and managerial efficiency. These constraints and the high operational costs preclude the routine and wide use of space application techniques, making them appropriate only for urban areas, emergency situations due to epidemics, or places where other simpler methods are inadequate. In rural areas they may be a supplement to other more permanent types of control operations.

The ultra-low-volume (ULV) technique of space application of insecticides is the most recent development in this field. It consists in applying highly concentrated or technical (undiluted) compounds to the air in the form of minute liquid particles. By reducing the volume and the weight of the insecticide per unit of area treated, operational logistics and costs are considerably reduced.

Malathion, pyrethrum compounds and naled are commonly used in mist, fog or ULV applications.

3.3 Biological methods

3.3.1 Introduction

Biological methods of mosquito control basically consist in the utilization of natural enemies of the mosquitos and of biological toxoids to achieve an effective control.

For many years it has been observed that certain plants, invertebrate predators (such as Toxorhynchites), and vertebrate animals (such as frogs, fish and ducks) feed on mosquito eggs and larvae or ingest them while picking on other food. Except for fish, these agents have not yet been used on an operational scale in mosquito control programmes, and it is only recently that comprehensive studies have been undertaken of their potentiality as effective biological agents for mosquito control.

To be effective, biological control agents should be used in a sufficiently large number. Usually the indigenous species should be given first priority. The introduction of exotic species calls for caution since unexpected adverse effects on local fish and on the environment have resulted from such introductions in the past.

3.3.2 Larvivorous fish

The Gambusia fish is a voracious eater of mosquito larvae and, if introduced in sufficient numbers in pools, ponds and marshes, it can destroy large quantities of mosquito eggs, larvae and pupae. The fish are small, are capable of penetrating vegetative protective cover, and can survive in the absence of mosquito larvae as a source of food. They multiply rapidly (200-300 per female). They need no special habitat for oviposition since they are viviparous as well as resistant to wide ranges of water temperature and water quality. Another larvivorous fish commonly used for mosquito control is the guppy (Poecilia reticulata).

3.3.3 Invertebrate predators

Invertebrate predators play an important role in the natural regulation of mosquito populations. Most of them, however, have biological characteristics preventing their mass production for biological control purposes. One outstanding exception is represented by mosquitos of the genus Toxorhynchites, whose several species can be mass-produced.

Toxorhynchites females do not bite at all, and the larvae have predatory habits. Toxorhynchites are promising enough for the control of Aedes mosquitos breeding in plant axils, tree holes, cut bamboos, abandoned containers and similar sites. More investigation is required, however, before the operational feasibility of vector control campaigns based on Toxorhynchites releases can be established.

3.3.4 Nematodes

A large number of mermithid species from mosquitos have been described. Several of these have a broad enough mosquito host spectrum to constitute promising biological control agents and at least one of these, Romanomermis culicivorax, has been mass produced for large-scale evaluation in the temperate and tropical zones. The potential of the mermithids for the control of ground pool and ricefield mosquitos could be rather high, wherever they can recycle at operational levels once introduced.

3.3.5 Protozoa and fungi

A number of protozoal and fungal agents affecting mosquitos are under evaluation to determine their potential under laboratory conditions and in small-scale field trials. Each of these agents can be mass produced either through well known fermentation methods or at least through cottage industry processes. Many problems related to industrial production, shelf life and formulations need to be solved, however, before the most promising of these agents become operational.

3.3.6 Bacteria

Some spore-forming bacteria, and in particular certain strains of Bacillus thuringiensis and B. sphaericus, produce bacterial toxins which are lethal to mosquito larvae but are innocuous to most non-target aquatic organisms and to vertebrates. They therefore constitute environmentally safe larvicides. Larvicide formulations derived from the serotype H-14 of B. thuringiensis are on the verge of industrial production and those based on the strain 1593 of B. sphaericus might be marketed soon afterwards. Several other promising strains have recently been isolated. The development of a variety of safe larvicides might obviate the consequences of resistance to conventional chemical insecticides.

3.4 Genetic control

Several genetic methods of mosquito control are being studied under laboratory conditions, and a few, including release of sterile males to reduce fertility in a local target population, have been tested in field trials. Sterile males for mass release can be produced by the use of chemosterilants, by radiation causing chromosomal translocations, or through specific cross-breeding which produces sterile hybrids.

Another method makes use of cytoplasmic incompatibility. Attempts are being made to produce strains which are carrying favourable genes (e.g., refractory or non-susceptible to disease agents). Means exist to introduce these favourable genes into a harmful local population, and it may be possible to replace the local population by a favourable one through cytoplasmic incompatibility.

It is too early to judge the success of genetic methods of mosquito control. Success depends to a large extent on the results of trials at present underway or planned in the coming years.

3.5 Environmental management methods

These methods are dealt with in subsequent chapters.

4. Pest (nuisance) mosquitos and their control

The term "pest mosquito" is applied to all those mosquitos which, without necessarily transmitting pathogenic organisms, are of health importance because, by repeated biting, they have adverse effects on physical efficiency, mental rest, comfort and enjoyment of life.

Pest mosquitos are of medical importance since their bites may produce local pain, edema, dermatitis, itching and systemic reactions, and may open the way to secondary infections, directly or through rubbing and scratching. In some cases the itching may last for days with

consequent restlessness, loss of sleep, reduced efficiency and nervous irritation.

The economic effects of pest mosquitos include loss of manpower output, losses in milk, meat and, indirectly, crop production, and losses in the development and exploitation of recreational grounds and areas. For these reasons and because some pest mosquitos may become disease vectors, their control is needed.

Only those developed countries where disease transmission by mosquitos is no longer of primary health significance can afford specific programmes to control the pest mosquito population. Most developing countries will continue to concentrate their efforts against vector mosquitos. One of the advantages of environmental management is that, by reducing and suppressing the breeding habitats of vector mosquitos, it also reduces the population of pest mosquito species that use the same habitats for breeding.

Measures against pest mosquitos are directed to the egg, larva and adult stages by applying the techniques used against vector mosquitos. Operations are dependent on specific needs determined from reports of complaints, established nuisance levels, routine surveys, forecasts of floodwater elevations in a reservoir, proximity of breeding areas to places of human activity, use and occupation.

Table 1.7 of Annex 1 presents the important species of the most common pest mosquitos, including epidemiological data, their general distribution, adult habits, and breeding habitats.

Table 1.8 of Annex 1 presents a list of the principal pest mosquito species, classified according to the site where they are most active or cause most problems, their distribution in geographical regions, their preferred time for biting, their usual types of breeding habitats, and life cycle.

CHAPTER II

ENVIRONMENTAL MANAGEMENT FOR MOSQUITO-BORNE DISEASE CONTROL

CONTENTS

	<u>Page</u>
1. Definition and classification	28
2. Advantages of environmental management measures	29
3. Interrelationships with agriculture and other developments	30
4. Ecological impacts	30
5. Present status and future prospects	30

1. Definition and classification

The WHO Expert Committee on Vector Biology and Control^a in 1979 defined environmental management activities as follows:

Environmental management for vector control: The planning, organization, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to preventing or minimizing vector propagation and reducing man-vector-pathogen contact.

This approach, which should be carried out prudently and skilfully, is naturalistic and involves an attempt to extend and intensify natural factors which limit vector breeding, survival and contact with man.

Environmental management for mosquito control covers a wide range of works and operations (see checklist in Annex 2) which can be further classified and defined as follows:

(a) Environmental modification: "A form of environmental management consisting in any physical transformation that is permanent or long-lasting of land, water and vegetation, aimed at preventing, eliminating or reducing the habitats of vectors without causing unduly adverse effects on the quality of the human environment." Environmental modification includes drainage, filling, land levelling and transformation and impoundment margins. Although these works are usually of a permanent nature, proper operation and adequate maintenance are essential for their effective functioning.

(b) Environmental manipulation: "A form of environmental management consisting in any planned recurrent activity aimed at producing temporary conditions unfavourable to breeding of vectors in their habitats." Water salinity changes, stream flushing, regulation of the

^a WHO Technical Report Series, No. 649, 1980 (Environmental management for vector control: Fourth report of the WHO Expert Committee on Vector Biology and Control).

water level in reservoirs, dewatering or flooding of swamps or boggy areas, vegetation removal, shading and exposure to sunlight are examples of environmental manipulation activities.

(c) Modification or manipulation of human habitation or behaviour: "A form of environmental management that reduced man-vector-pathogen contact". Examples of this kind of approach include the siting of settlements away from vector sources, mosquito proofing of houses, personal protection and hygiene measures against vectors, and provision of such installations as mechanical barriers and facilities for water supply, wastewater and excreta disposal, laundry, bathing and recreation to prevent or discourage human contact with infested waters.

2. Advantages of environmental management measures

With proper planning, design and maintenance, environmental management operations can prevent, reduce or eliminate mosquito breeding. They offer a number of advantages over other methods of vector control.

(a) They are effective. Environmental management uses methods and techniques which in the past have proved effective in eliminating breeding sites or in reducing mosquito access to man.

(b) They have long-term effects. Once the works are implemented, they remain effective for years, with periodic maintenance.

(c) Their long-range costs are relatively low. Although the initial capital expenditure may be high, their effects are not usually confined to vector control (see below). Therefore a comprehensive view of long-range costs may show that they are competitive with those of other mosquito control operations.

(d) The cost of small-scale management operations is usually within the budgetary limits of mosquito-borne disease control programmes. In organized programmes, even an allocation of a small percentage of the programme budget will be adequate to produce appreciable results over a number of years. Long-term effects may release resources for expansion to additional areas.

(e) Additional benefits may be considerable, and mutually beneficial to agriculture and health. Better use of water and land in rural areas will contribute to the improvement and extension of agricultural crops, land preservation, etc.; better housing and recreational and sanitary facilities in urban areas can contribute to social development and higher standards of living.

(f) The adverse environmental impact may be slight. Environmental modification and manipulation can often be applied without causing serious adverse effects on environmental quality.

(g) Their application needs only routine safety precautions such as those related to the use of machinery. The protection of the labour force from the hazards associated with the use of some chemical pesticides is not required.

(h) They can effectively contribute to the prevention and control of other vector-borne and water-associated diseases such as schistosomiasis, onchocerciasis and diarrhoeal diseases.

The disadvantages of environmental management operations are mainly their high capital cost, the length of time required for completion, and the complexity of important works which require resources beyond those of most mosquito-borne disease control programmes. However, small-scale operations are feasible, can be incorporated in integrated control strategies, and applied in combination with other methods of vector and disease control.

The application of environmental management measures should always be preceded by thorough ecological studies to take maximum advantage of natural processes and to avoid unnecessary environmental changes.

3. Interrelationships with agriculture and other developments

Development activities, especially those related to land and water, may influence the presence and density of mosquito vectors both positively and negatively. For example, the impoundment of water by the construction of a dam will flood numerous isolated potential or existing breeding sites and thus obviate the need for difficult and expensive operations to keep the area clear of mosquitos. At the same time, the reservoir will produce a long shoreline where aquatic and semi-aquatic vegetation will thrive and may become a favourable site for mosquito production. The reduced flow in the river bed downstream of the dam may cause the formation of shallow pools and puddles where mosquitos can breed unless the comprehensive preventive measures discussed in Chapter III are built into the system.

The draining of marshes for land reclamation may have a positive influence by reducing the populations of certain mosquito species, but unless this work is carried out effectively over a wide area, the effect may be to shift mosquito breeding from one habitat to another.

The opening up of land for agriculture by the introduction or extension of irrigation is frequently followed by an increase in mosquito breeding in irrigation canals and drainage ditches, and in the incidence of mosquito-borne diseases. The proper design, operation and maintenance of these systems will contribute significantly to the prevention of such breeding and produce economic benefits.

Many major water resource development projects in tropical and subtropical countries may not achieve their social and economic objectives because of the related increase in incidence of parasitic diseases which seriously impair the health and productivity of the population.

4. Ecological impacts

Environmental modification and manipulation consist basically in modifying the topographical, hydrological and biological patterns in mosquito habitats so as to render them unsuitable for mosquito breeding. Environmental management for mosquito control, while it makes the best use of materials and natural processes existing in the environment, cannot be expected to be entirely free from environmental impact, and this needs study at the design stage.

The ecological impact of environmental management may, in principle, be forecast by analysing the positive and negative effects likely to be produced by each of the proposed works and operations. However, there are no common criteria for the measurement of ecological effects that would give values for a quantitative assessment of impacts. This also applies to health benefits and detriments which, although clearly and generally perceptible, sometimes cannot be subjected to quantitative analysis.

The difficulty of assessing ecological effects does not imply that these efforts should not continue. Appraisals based on facts and unbiased judgement can produce useful data to guide planners and decision-makers. A degree of subjective evaluation may be needed in rating the suitability of various alternatives.

For the study of the interactions that may be involved in the analysis of impact on an ecological system, the use of a format or matrix may be helpful. A sample of a matrix prepared for the analysis of the ecological impact of the construction of a dam and reservoir is presented in Annex 3. This can also be adapted to analyse the ecological impacts of vector control measures being applied by a malaria control programme.

5. Present status and future prospects

Much is known about environmental modifications and its efficacy in controlling mosquito production. Major works involving the transformation of the pattern of land, water and vegetation, carried out mostly for other purposes, have contributed in many areas to the reduction of mosquito breeding. In some other areas, however, experience has shown that when the health implications of the environmental changes produced by the project have not received timely

attention, an intensification of vector-borne diseases has resulted.

Major environmental management works, such as the construction of dikes and levees, drainage of swamps and marshes, correction and straightening of waterways, and construction of flood control and diversion structures, are the responsibility of specialized agencies with appropriate financial and organizational resources. Such works are planned for flood protection, land reclamation, navigation, irrigation, fish production, etc., and require substantial investment. Fortunately the agencies responsible for development projects, particularly those dealing with water resources, are becoming increasingly conscious of the need to prevent the occurrence and intensification of vector-borne diseases.

Programmes for the control of mosquito-borne diseases can benefit much from these development schemes if vector control specialists are allowed to collaborate in preconstruction surveys, planning, design, construction and operation. They can propose realistic modifications so that such schemes can contribute to the reduction and elimination of mosquito sources.

Small-scale environmental management operations are sometimes within the scope of malaria control programmes, and can be carried out as part of the general control strategy. At present only a few health programmes make use of these methods in their operations. Other available methods which produce quick results have been preferred. However, the concept of integrated control is now more widely accepted and put into practice. Environmental modification operations can be adjusted to suit programme requirements and resources, and offer a practical contribution to integrated mosquito control strategies. Their use is expected to expand in the near future.

As in any other human activity, proven methods are doomed to failure if they do not meet the required standard of performance because of lack of intelligent planning, clear understanding, conscientious application and firm perseverance.

CHAPTER III

ENVIRONMENTAL MODIFICATION

CONTENTS

	<u>Page</u>
A. Impoundments	33
B. Irrigation	43
C. Natural streams	65
D. Drainage for agriculture and land reclamation	70
E. Drainage for mosquito control	83
F. Land filling and grading	102
G. Settlement of population and protection of work force	107
H. Equipment for environmental management	110
Further reading list	114

IIIA. IMPOUNDMENTS

Contents

	<u>Page</u>
1. Introduction	33
2. Mosquito problems in impoundments	34
3. Reservoir design and construction	35
3.1 General remarks on design	35
3.2 Special considerations for mosquito control	36
4. Environmental modification measures for mosquito control	37
4.1 Reservoir site clearing	37
4.1.1 General considerations	37
4.1.2 Special situations	37
4.1.2.1 Clearing on shorelines subject to erosion	37
4.1.2.2 Clearing at heads of bights and indentations	39
4.2 Drainage of reservoir margins	39
4.3 Deepening and filling	39
4.4 Diking and dewatering	41

1. Introduction

Water availability is uneven both in space and in time. Rainfall and runoff are quite variable from place to place, year to year, and season to season. Even in the temperate zone, some places have too much rainfall and other places little or no rainfall. There is thus a need to develop some man-made water resource management.

A key factor in water management is storage. Impoundments are reservoirs for the storage of runoff behind man-made dams. They collect excess runoff during rainy seasons for subsequent release for power generation, water supply, irrigation and other beneficial uses. In some instances, they enable flood water to be held back to avoid downstream damage.

A recent review of reservoir construction reveals that 14 large man-made lakes are located in tropical and subtropical countries in Asia, Africa and Latin America. The Volta, Nasser, Kariba and Cabora Bassa lakes in Africa are among the largest in the world and schistosomiasis is increasing alarmingly in extent and intensity among the populations settled nearby. The current oil prices have increased the economic advantage of hydropower generation, and studies predict that a large number of reservoirs will be built in tropical Africa in the 1980s. These projects may result in further spread of water-related diseases unless appropriate preventive measures are taken.

Impoundments may be constructed in such a way as to minimize vector breeding along their shores, and precautions should be taken in designing them to that end. The shortage of trained engineers, especially in the developing countries, is one of the reasons why good principles of reservoir design have generally been neglected.

2. Mosquito problems in impoundments

The flooding of a vast area as the result of a dam can have a beneficial effect in controlling mosquito production. The large number of isolated and scattered breeding sites in the basin, so difficult to identify and treat with larvicides before impoundment, are submerged when the area is flooded to form the reservoir. Thus innumerable small but difficult problems are exchanged for one large but clearly defined problem which may be easier to manage.

It has been repeatedly observed that, in the absence of floating mats of vegetation, mosquitos do not breed in the deep waters far from the reservoir margins. Nor is there any significant mosquito breeding along the steep, main shoreline exposed to wave wash. The areas of the impoundment subject to mosquito problems lie within protected bights, hollows and indentations of the shoreline. The water in such places is usually shallow and filled with aquatic vegetation and floating material where mosquito larvae find the necessary protection from currents, wave action and wind as well as essential food and cover from natural enemies.

The magnitude of the mosquito problem in impounded waters is in direct proportion to the length of the marshy shoreline. As an indication of the relative importance of any reservoir as a source of mosquito breeding, a "marsh potential"^a has been derived as a parameter based on the following formula:

$$\frac{\text{Shoreline length(m)} \times \sqrt{\text{Reservoir area(m}^2)}}{\text{Reservoir volume(m}^3)}$$

The unit in which marsh potential is expressed is (from the above formula) $\text{m}^{2/3} \times \text{m}^{-3}$, i.e., m^{-1} (reciprocal metre).

For shallow run-of-the-river reservoirs with a small mean depth (volume/area) or where the number and size of bights and indentations caused by streams and ravines produce a very long shoreline, the marsh potential may be as high as 18 to 20m^{-1} . For a deep reservoir with steep slopes in a mountainous area, the marsh potential may be 2 to 3m^{-1} . Obviously the former situation has a much greater potential for creating mosquito problems than the latter.

Another general observation is that the marshy margins of the reservoir are not uniformly distributed over the whole shoreline. If the reservoir is divided into three portions, as indicated in Fig. IIIA-1, the middle portion with shallow areas, emerging islands and extensive shoreline will produce more mosquitos than the portion near the dam, usually deep and enclosed between steep margins with much wave action and erosion, or than the distant portion at the tail of the reservoir, where water may be shallow but contained by the natural banks of the river. At the design stage of the reservoir, when several alternatives for the location and height of the dam are proposed, one criterion for the selection should be the relative length of the prospective shoreline, as the shorter it is the lower will be the potential for mosquito breeding.

The potential for mosquito breeding should be kept in mind also when selecting sites for relocating the communities from areas that will be submerged when the impoundment is full and for establishing new settlements. The problem of village siting is dealt with in Chapter V, Reduction of man/mosquito contact.

^a Developed by C.W. Kruzé in rating the reservoirs of the Tennessee Valley Authority against the potential mosquito control cost.

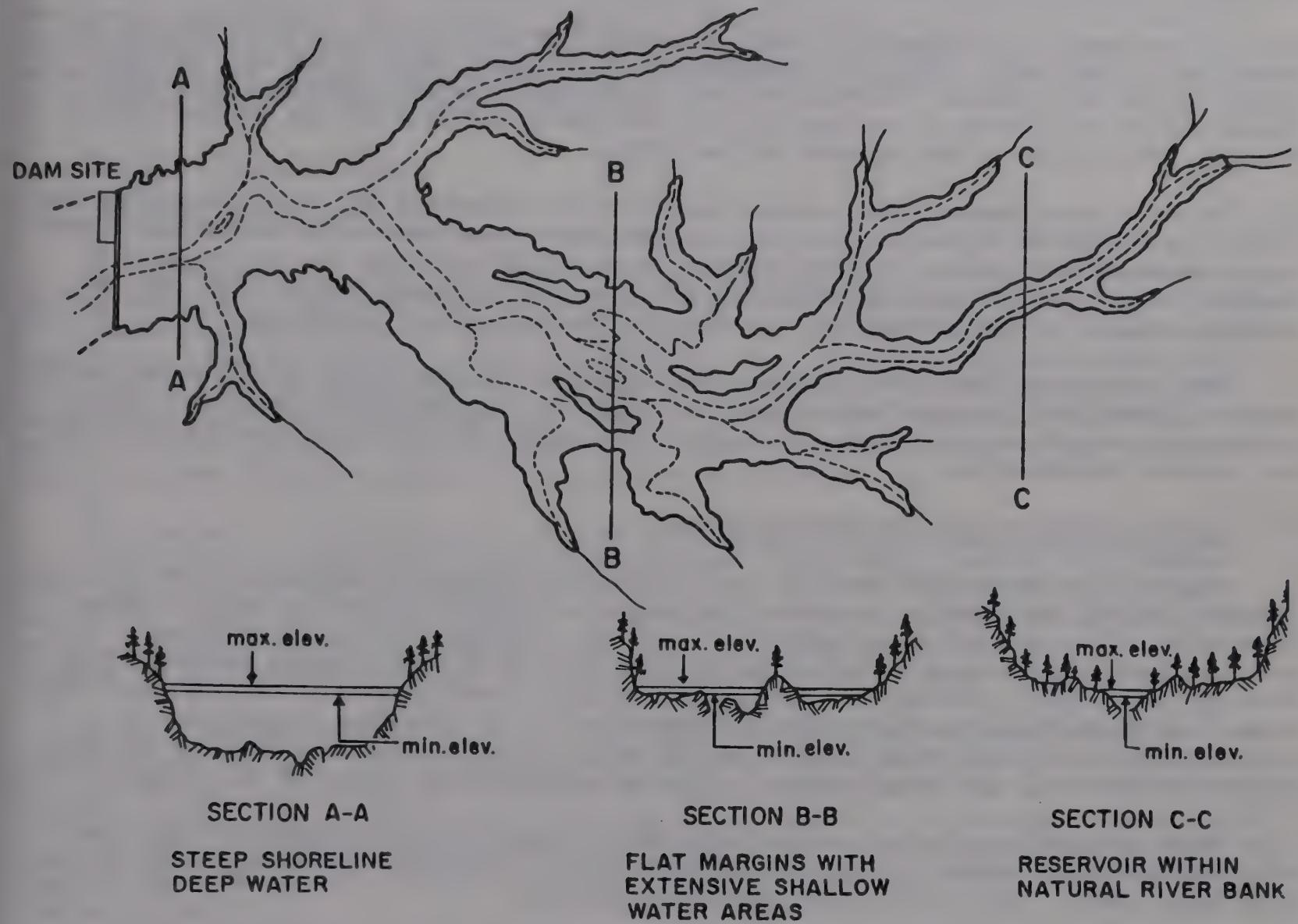


Fig. IIIA-1. Generalized view of an impoundment showing the greatest mosquito production potential in the middle third of the area of impounded water where shallow water and protected areas, often invaded with vegetation, provide the optimum habitat for pond-breeding anophelines.

3. Reservoir design and construction

3.1 General remarks on design

The design of reservoirs involves a group of professionals including hydrologists, geologists, civil and structural engineers, and soil mechanics specialists. The design must be based on thorough knowledge of:

- (a) The hydrology of the river basin. Hydrological data are essential in estimating the dependable yield of the watershed which is a critical factor in any impoundment project.

(b) The geology of the river basin. The character of the subsoil at the proposed dam site is of primary importance since on it depends the stability of the dam foundations. The permeability of the soil in the area that is to be flooded is also important as it will provide an indication of the water-holding property of the proposed reservoir.

(c) The topography of the catchment area, in general, and of the area to be flooded by the reservoir, in particular. The land configuration on the river basin is the most decisive factor in reservoir design; it should be such as to permit the impoundment of water while inundating the least area of land and using the minimum of material for the construction of the dam. This is one of the criteria for dam siting.

(d) The water requirements. The storage capacity of the reservoir and the corresponding dam height are determined on the basis of the estimated water requirements for the various intended purposes of the project. If flood control is one of the purposes, the project will be designed for a given statistical probability of storms and consequent flood flows, and the storage capacity must be adequate for the requisite control of such situations.

When calculating the volume of water to be stored in the reservoir, the following losses must be allowed for: seepage loss through the bed of the flooded basin; water loss due to evaporation, particularly in areas of hot and dry climate; and loss of storage capacity due to reservoir sedimentation.

3.2 Special considerations for mosquito control

Reservoirs in mountainous areas do not offer a serious mosquito control problem if certain measures are applied prior to impoundment and proper maintenance is carried out afterwards. Reservoirs in flat terrain present more difficulties. Inundated flat lands are usually associated with fertile soil and plant growth, particularly in those margins protected from wind and wave action. The smallest lowering of the water level uncovers a wide marginal zone because of the very slight slopes along the shoreline. It is therefore obvious that for mosquito control, the following items of work should be given special consideration and need to be provided for in the budget during the design and subsequent phases of the project:

(a) Proper preparation of the reservoir site, and in particular the clearing of trees and other vegetation, to ensure a clean water surface at all elevations between high and low operating water levels. This is also good engineering practice.

(b) The necessary provisions for fluctuating the water level in the reservoir, whenever feasible, during operation of the project. Water-level fluctuation as an environmental manipulative measure for mosquito control is discussed in Chapter IV, section 1.3. Any special requirement for spillway control gates for this purpose should be incorporated in the dam and reservoir design.

(c) Suitable marginal drainage to avoid leaving isolated pools along the reservoir margins when the water level has fluctuated.

(d) Permanent works, where economically feasible, to eliminate vast shallow areas on the margins of the reservoir close to high population areas.

(e) An effective programme for shoreline and drainage maintenance, vegetation growth control, and drift removal after the reservoir has been filled.

Environmental modification methods for mosquito control, particularly in relation to items (a), (c) and (d) above, are discussed in the following section.

4. Environmental modification measures for mosquito control

These measures of environmental modification are mostly directed to the preparation of the reservoir site and to the shortening and improvement of the reservoir shoreline. Mosquito problems in impoundments are generally limited to the shoreline zone (see section 2 above). If the shoreline is shortened by works to produce straighter alignments and at the same time improved to render it less favourable to vegetation growth and mosquito breeding, the chances of successful mosquito control will be enhanced.

4.1 Reservoir site clearing

4.1.1 General considerations

Past experience has shown the adverse effects of failure to clear sites of man-made lakes. The basin must be cleared or otherwise prepared prior to filling so that a clean water surface will result at all elevations of the operating zone. This involves removal of trees, under-brush, vines, fences, bridges, houses, barns, sheds, etc., which otherwise would disintegrate and decay, and perhaps float, drift to the shore, and accumulate at the heads of bights and indentations where such flotsam encourages aquatic plant growth and mosquito production. For mosquito control purposes it is not necessary to clear the deeper portion of the reservoir where all timber would be permanently and completely submerged.

With regard to the clearing of trees and other vegetation, compromises may have to be made to meet difficulties arising from project purpose, topography, expected wide drawdown range, and cost. At the design stage of the reservoir, field surveys and studies should be carried out to forecast possible changes in the ecology of the future margins and their effect on mosquito production. If, as a compromise, clearing has to be selective, the findings of such surveys can serve as a basis for delineating the areas to be cleared.

Another consideration for selective clearing is the distance from human habitation. In general, areas far away from villages and with difficult accessibility are not as important as those located in the vicinity of human activities. Theoretically, the notion of "vicinity" should be interpreted as within the flight range of the confirmed or suspected local mosquito vectors. For practical purposes, however, it is sufficient to allow for a range of 1.5-2 km from the human habitation in order to provide a reasonable degree of protection (see also Chapter V, section 1).

Advantage should be taken of the timber and other salvageable material of commercial value in the basin. Where a market exists and the trees and other material can be transported without excessive costs, their sale may offset significantly the cost of clearing. The remaining brush and waste materials must be piled and burned.

The construction and subsequent total filling of a large reservoir will take a number of years and therefore the clearing operation may span several seasons. By careful scheduling of clearing operations, regrowth prior to flooding may be minimized in the shallow margins of the reservoir which present the more serious potential mosquito problems. Reclearing just prior to flooding may be required in critical areas. A carefully planned shoreline maintenance programme after impoundage is imperative in many reservoirs for effective mosquito control.

4.1.2 Special situations

4.1.2.1 Clearing on shorelines subject to erosion

One of the most striking changes along the margin of newly impounded reservoirs occurs on the banks exposed to wave wash from a wide expanse of water. Depending upon the extent of the open water and the geological formation of the bank, the slope of the bank receiving the brunt of the wave erosion transforms into a cliff rising from an erosion terrace or beach. In time, this beach will become stabilized at a slope of about 8:1 at the most common operating water-level of the impoundment, and during the stabilization period a band of trees above the clearing line may fall into the reservoir.

It is good practice to determine in advance the margins where erosion will take place and to remove the trees that risk falling into the lake prior to impoundage. Fig. IIIA-2 gives the empirical formula for estimating the limits of additional clearing for erosion along reservoir margins exposed to wide expanses (wave fetch) of water.

Some of the newer African impoundments, such as the Volta dam, are more than 32 km wide in certain places and on the steeper exposed shorelines it may be necessary to cut trees out of a zone 30 m beyond the reservoir high-level line.

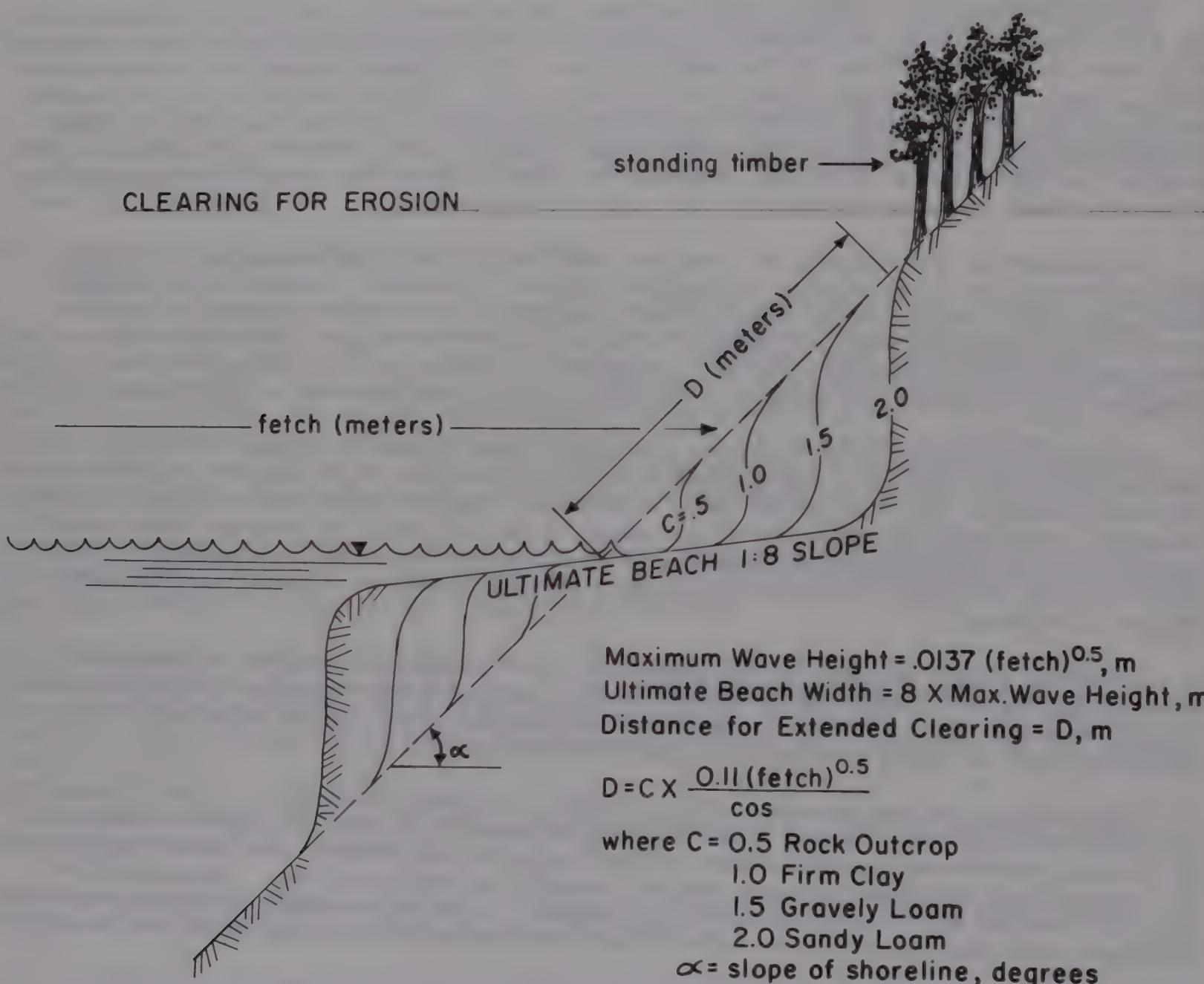


Fig. IIIA-2. Clearing for erosion.

NOTE: The pre-impoundage clearing of timber must extend beyond the basic clearing line in anticipation of bank erosion which varies with the exposure to wave wash, bank slope and soil conditions.

4.1.2.2 Clearing at heads of bights and indentations

In reservoirs for flood control or having flood control as one of their purposes, heavy mats of logs and other floating debris may be trapped in the heads of bights and indentations after floods. If they are held or fail to strand, they will protect aquatic vegetation and mosquito larval habitats. In flood storage zones that are not totally cleared of timber, an area at the heads of bights and indentations should be cleared back at least 8 m from the clearing line to provide necessary space for stranding and subsequent piling and burning of accumulated drift.

4.2 Drainage of reservoir margins

Marginal drainage must be provided for in the zone between the maximum and minimum water levels of the reservoir. This means that all discernible depressions lying in this zone, which could form isolated pools sufficiently permanent to produce mosquitos when the water is lowered, should be connected with the main body of the reservoir by suitable drainage structures. The myriad of small puddles, hoofprints and the like which can dry up in a few days through evaporation do not require marginal drainage. Areas that remain in a permanent boggy condition due to the existence of subsurface springs also need to be drained. Chapter IIIE deals in detail with drainage for mosquito control.

4.3 Deepening and filling

Where a large population is to be protected, the shallow margins of a reservoir (with a high mosquito production potential) can be made unsuitable for mosquito breeding through topographical alteration. Such alteration may be accomplished by (a) filling the marginal problem zones to a level above the maximum water level of the impoundment, (b) deepening the problem zone to a depth below the lower limit of marginal growth invasion, or (c) a combination of (a) and (b). Normally, the most economical procedure would be (c) which helps balance the quantities of cut and fill and reduces the distances the earth has to be moved without decreasing the storage volume of the reservoir. The deepening at the shoreline zone to 1m or more will reduce the growth of aquatic plants and expose the edge to wave action; both will discourage mosquito breeding.

A deepening and filling operation is usually combined with shoreline reshaping, by taking earth from land projections to fill indentations or bays. Thus, in addition to eliminating favourable mosquito breeding sites at shallow margins, the operation will result in shorter and straighter shorelines, directly reducing the length of the potential breeding sites.

Good topographical maps are required for planning and designing a cut-and-fill project. Contours at 30 cm intervals in maps of the proposed improvement area are necessary if the earthwork involved is to be accurately estimated. Detailed plans should be developed using maps to a scale of about 1/5000, and should indicate, among other things, the cut-and-fill areas and the new shoreline. It will be advisable to permit field adjustments in the course of the work to deal with any unusual or unforeseen conditions that might develop.

Conventional earth-moving equipment such as tractor-scrapers, bulldozers or graders may be used in the cut-and-fill operation, except in boggy conditions where a dragline may be suitable (see subchapter IIIH, sections 3 and 4). Drainage works may be installed in marshy areas to improve ground conditions ahead of the main operation.

Cut-and-fill measures were used extensively for the first time by the Tennessee Valley Authority (TVA) in the Kentucky reservoir where they are an important part of the permanent shoreline improvement programme. A plan and profile of the TVA deepening-and-filling project are shown in Figs. IIIA-3 and IIIA-4.

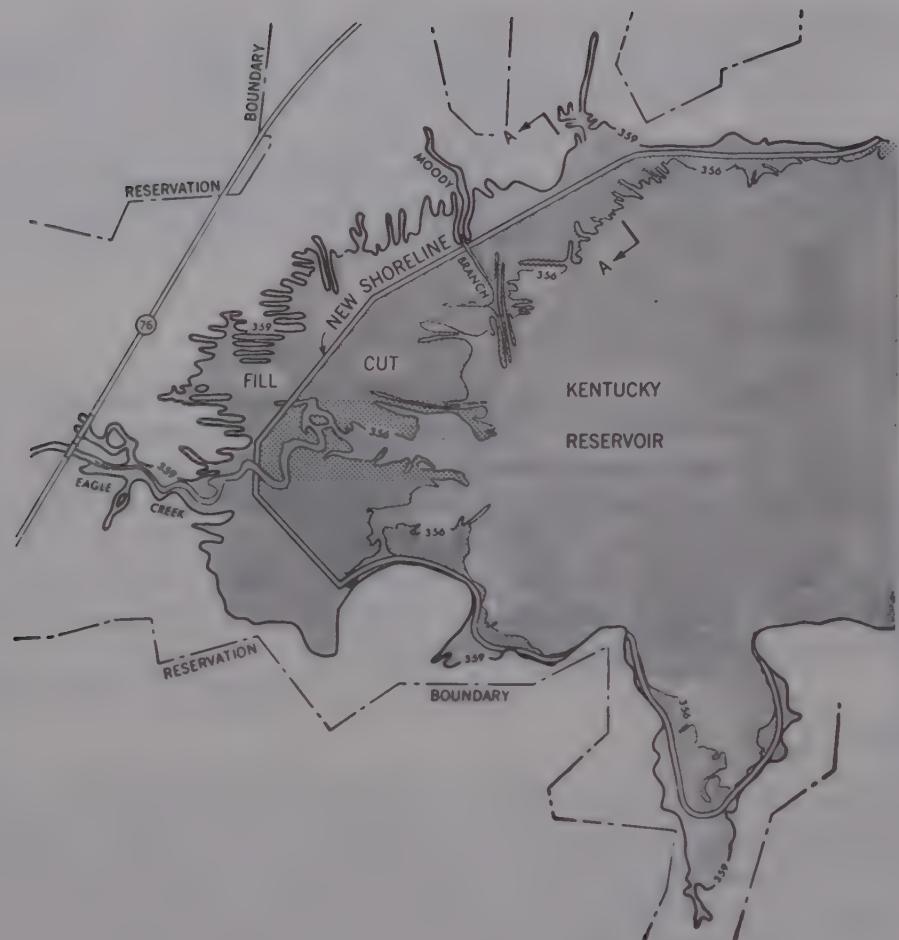


Fig. IIIA-3. Plan map of a cut-and-fill project — Eagle Creek, Kentucky Reservoir.*

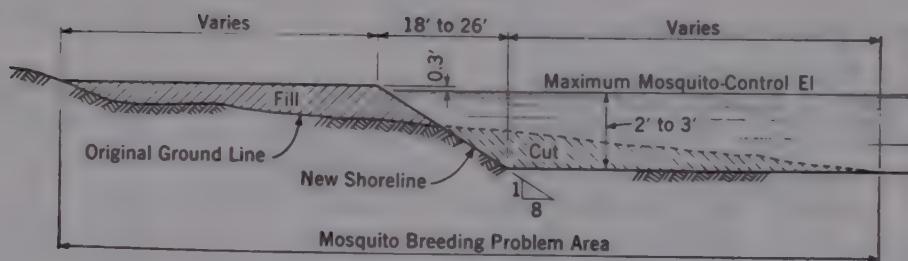


Fig. IIIA-4. Diagrammatic cross section of a cut-and-fill project.*

*Reproduced from: Malaria control on impounded waters. Washington, DC, United States Public Health Service, Tennessee Valley Authority, 1947.

The capital investment for a deepening-and-filling operation is high; however, very little maintenance is required afterwards. With the low interest rates prevailing at the time (1947), TVA estimated that the expected savings in mosquito control costs (the difference between the total costs without and with the deepening-and-filling operation) would be more than enough to amortize the investment during the expected life of the project. This estimated cost comparison, together with pertinent data from one of the TVA Kentucky reservoir deepening-and-filling projects, is shown in Table IIIA-1. Even though conditions have changed, similar savings would be possible today.

Table IIIA-1. Eagle Creek deepening-and-filling project summary,
Kentucky Reservoir, Tennessee River*

Length of shore line before filling.....	miles	11.5
Length of shore line after filling.....	miles	2.9
Mosquito problem area filled.....	acres	78.8
Mosquito problem area deepened.....	acres	76.3
Total problem area eliminated.....	acres	155.1
Population within 1-mile zone.....		365
Population density per square mile.....		57
Earth moved in deepening and filling.....	cubic yards	128,000
Cost of project including clearing, excavation, etc.....		\$50,500
Annual costs:		
Mosquito control without deepening and filling:		
1. Larviciding		\$1,900
2. Growth removal		1,600
3. Drainage maintenance		500
		4,000
Mosquito control with deepening and filling:		
1. Larvicides		\$ 300
2. Growth removal		100
3. Drainage maintenance		200
4. Interest on capital investment @ 3 percent.....		1,500
5. Annual amortization cost for 25-year period @ 3 percent		1,400
		3,500
Estimated annual savings.....		500

*Reproduced from: Malaria control on impounded waters. Washington, DC,
United States Public Health Service, Tennessee Valley Authority, 1947.

4.4 Diking and dewatering

Where deepening and filling would involve major earth-moving operations, it may be necessary to consider the possibility of building dikes or levees to isolate large shallow bays for reclamation by dewatering. Such areas, if remaining inundated, could provide numerous mosquito breeding places which would be extremely difficult to control.

In order to protect the dewatered area from excessive runoff and flooding, action should, if possible, be taken to channel drainage from the upland watershed either through or around the area. A drainage system should also be installed within the area to collect and convey the surface runoff to a pumping station of adequate capacity, suitably located at the lower end of the area and adjacent to the dike. It is advisable to include a gate-controlled gravity-flow structure for the drainage of the diked area into the reservoir when the water level in the latter is low enough. Spillways of adequate capacity should also be provided to protect the dike from being overtapped during anticipated (or unexpected) high water in the dewatered area.

The character of the soil is an important consideration in the design, construction and maintenance of dikes, ditches and spillways. A geological investigation of the underlying formation is necessary to determine whether seepage may be expected in the dewatered area. The accumulation of relatively minor seepage from a large area might result in excessive pumping costs and affect the economics of the project.

For mosquito control purposes, it would be acceptable if the area could be dewatered within 5-7 days after flooding. However, if the dewatered area is used for agricultural purposes, the dewatering schedule should take account of the agricultural requirements, and the pumping station should be designed accordingly.

Diking and dewatering were used rather extensively for mosquito control in the Kentucky reservoir by the Tennessee Valley Authority. A general plan and a cross section of a TVA dewatering project are shown in Fig. IIIA-5. The method has been used in the Netherlands, but not for mosquito control alone. It has also been widely used in agricultural drainage and flood protection projects. Although it provides considerable benefits in mosquito control, this method should be viewed rather in terms of other advantages such as land reclaimed or protected, or improved agricultural returns. For example, economic justification for three of the larger TVA projects in Kentucky was based principally on reduced costs for the protection of highway and railroad fills traversing the areas. Furthermore, all 10 of the TVA diking and dewatering projects originally constructed for mosquito control are now operated primarily in support of wildlife interests, but without loss of the other benefits mentioned above.

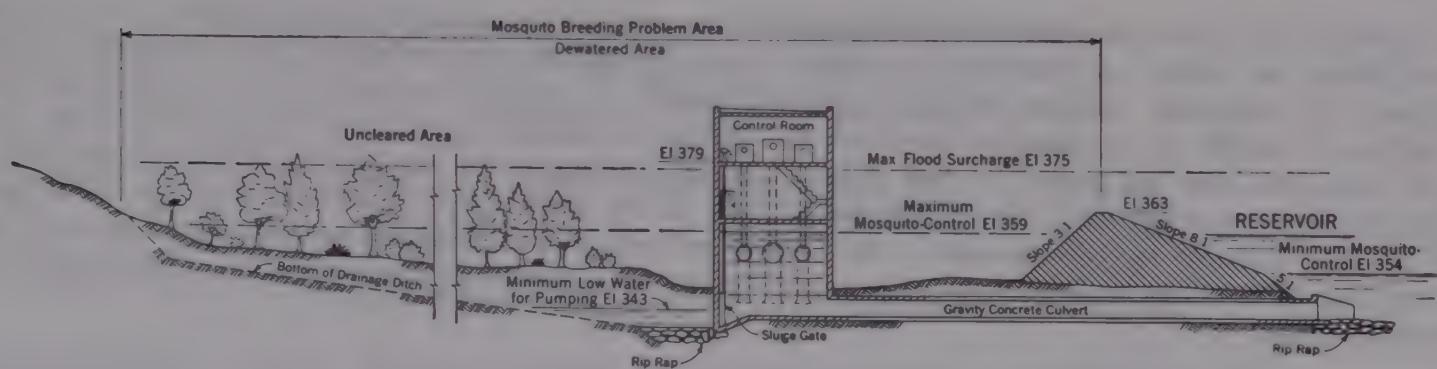
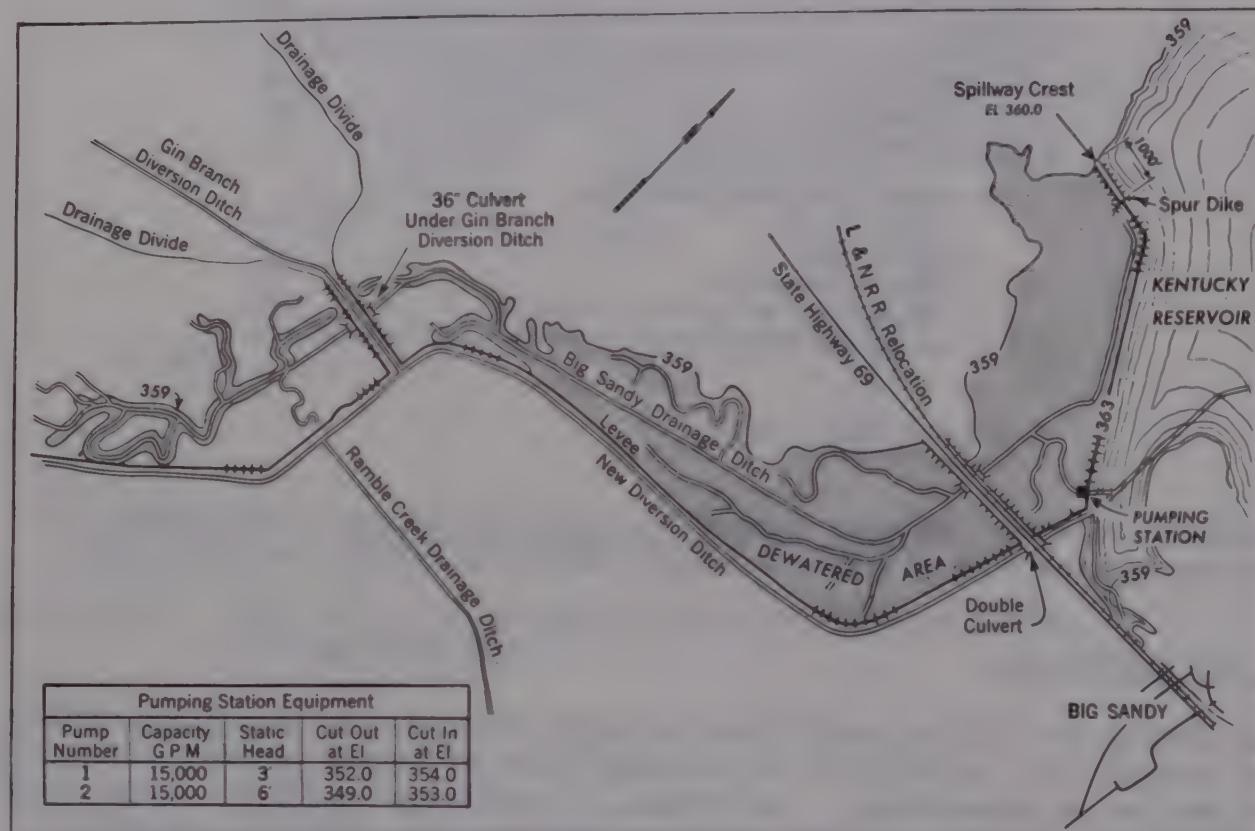


Fig. IIIA-5. General plan and sectional view of a diked and dewatered area of Big Sandy River of the TVA Kentucky reservoir. The flow of Big Sandy River is diverted around the area so that only a modest pumping capacity is required within it.

Reproduced from: Malaria control on impounded waters. Washington, DC, United States Public Health Service, Tennessee Valley Authority, 1947.

IIIB. IRRIGATION

Contents

	<u>Page</u>
1. Introduction	43
2. Types of water conveyance structures for irrigation	44
2.1 Open canals	44
2.2 Pipe conduits	44
3. Irrigation methods	45
3.1 Uncontrolled or "wild" flooding	45
3.2 Border-strip flooding	46
3.3 Contour check flooding	46
3.4 Basin flooding	46
3.5 Furrow irrigation	46
3.6 Subirrigation	47
3.7 Sprinkler irrigation	47
3.7.1 Mechanized sprinkler irrigation	48
3.7.2 Localized sprinkler (trickle or drip) irrigation	50
4. Mosquito problems in irrigation systems	51
4.1 In canals	51
4.2 On the land adjacent to canals	51
4.3 In the cultivated fields	52
5. Design of irrigation systems	52
5.1 General remarks on design	52
5.2 Special considerations for mosquito control	54
6. Canal lining	56
6.1 Paved or hard surface	57
6.2 Membranes	57
6.2.1 Exposed membrane	57
6.2.2 Covered membrane	58
6.3 Compacted earth	59
6.4 Earth and chemical sealants	60
6.5 Service life and comparative costs	60
7. Curves in canals	63
8. Gates and siphons	64

1. Introduction

Irrigation is the application of water to the ground primarily for maintaining the soil moisture conditions that are most suited to plant growth and crop production.

Irrigation produces incontestable benefits but also brings with it the constant menace of disease and disability. In numerous tropical countries the increase of such major diseases as malaria and schistosomiasis can be traced to the development of irrigation.

Many of the health hazards connected with irrigation can be prevented or at least reduced by measures taken in the planning, design, construction and operation of irrigation systems. If irrigation engineers and planners are informed about the environmental conditions that favour the breeding of disease vectors, they will be able to avoid or minimize the creation of such conditions. Likewise, vector control operators will benefit by acquiring a clearer picture of the systems, methods and techniques of irrigation, their applicability, scope and limitations.

2. Types of water conveyance structures for irrigation

2.1 Open canals

The earth canal is still the most commonly used structure for conveyance of water for irrigation. It is one of the oldest and simplest engineering works for water resources development.

The cross-section of earth canals is usually trapezoidal, with the sides as steep as the material will stand when exposed to flowing water. The slope of the sides (ratio of horizontal to vertical projections) varies from 3:1 to 1:1 depending on the consistency of the soil. The central section or bed of the canal is horizontal in a newly dug channel.

Earth canals should be stable, i.e., they should maintain their original shape so that their water-carrying capacity is not altered. Ideally, neither deposition of sediment nor scouring should take place in the canal. As a high flow velocity scours the channel and a low velocity allows silt deposition, canals are in practice usually designed with a water velocity between the two extremes. Water velocity in canals is discussed in section 4.2 of Chapter VII.

The major advantage of earth canals is their low initial cost and their simplicity of construction. Where a labour force is readily available, canal digging provides employment for a large number of unskilled workers.

The disadvantages of earth canals are:

- (a) high seepage and conveyance water losses, and the resultant waterlogging of adjacent land;
- (b) danger of bank breakage caused by overtopping, erosion and animal burrowing; (c) profuse growth of aquatic weeds which retards the flow and gives rise to heavy maintenance costs;
- (d) low operating velocities requiring large cross-sectional areas, thus a wide strip of land is occupied; (e) deterioration of the original section, reducing the capacity and requiring frequent trimming and reshaping; (f) the need for bridges to prevent destruction of section.

These disadvantages may be reduced or overcome by lining earth canals. The subject of canal lining, including its advantages and economics, is dealt with in detail in section 6 of this subchapter.

2.2 Pipe conduits

Pipes or closed conduits are sometimes used for conveyance of water for irrigation. While a piped system may be more expensive in certain instances, a decision in favour of an open channel system should be based on a sound economic analysis. It is interesting to note that, mainly because of the smoothness of its surface, a concrete pipe of 0.6 m diameter has about the same water-carrying capacity by gravity as a canal 1.4 m wide at the water surface level, 0.5 m deep, and 0.3 m wide at the bottom, providing the slope and other conditions are the same. The carrying capacity of the pipeline, when working under pressure, can be further increased without producing undue stresses that may cause leakage at the joints. If there is a need to convert existing canals, it may prove economical to replace them with closed conduits rather than to line them in open sections.

Pipes are required for water conveyance when water must be pumped, whether to overcome differences in ground elevations or to lift it from underground sources.

Pressure piped systems are buried at a sufficient depth to protect them from damage by ploughs and other agricultural equipment, so that the land strip above may be used for crop production. Irrigation water is delivered where needed through conveniently spaced riser pipes fitted with valves; the system may also be combined with sprinkler irrigation (see section 3.7 below).

The advantages of buried pipelines are: (a) the layout is not restricted by topographic configuration, slopes, streams, roads, irregularities, etc.; (b) the conveyance system does not take away any land from cultivation; (c) the movement over the land is free from obstruction; and (d) there is no mosquito breeding (or aquatic plants) to control.

The principal disadvantage of pipe conduits is that the water used has to be fairly free of sediment. Underground water usually presents no problem, but turbid surface water may need settling before it is introduced into the pipe network. Periodic flushing of pipelines may be necessary to remove accumulated sediment.

3. Irrigation methods

Various irrigation methods have been devised to meet particular situations in topography, water supply, crops, customs and agricultural practices. The most common methods (see Fig. IIIB-1) are described below.

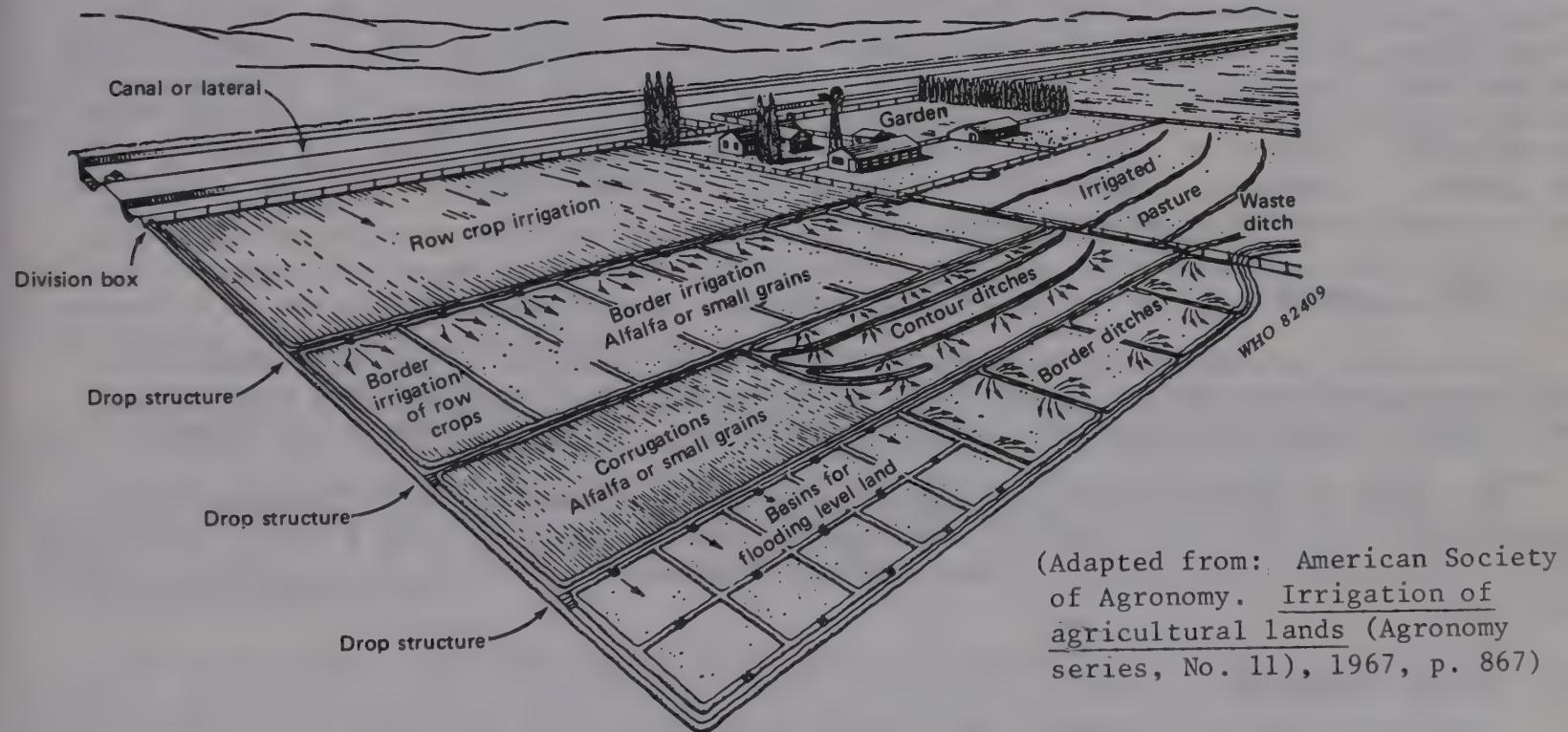


Fig. IIIB-1. Various methods of applying water to field crops.

3.1 Uncontrolled or "wild" flooding

This is the oldest method applied to even and flat lands. The land requires the minimum of preparation; the water that overflows from the supply canal runs freely over the surface in an erratic way. If the flow over the land is too rapid, insufficient water will percolate; if the water is held too long, much of it will seep beyond the root zone. In either case, water losses are so great that wild flooding is suitable only where water is abundant and cheap.

This method was practised 5000 years ago in Egypt by diverting the annual high flow of the Nile to cover vast tracts for agricultural cultivation. It had the advantage that the rich loam of the Nile water remained on the ground when the flood receded, thus fertilizing the soil and increasing the top soil layer of arable land year by year.

3.2 Border-strip flooding

The method of border-strip irrigation controls the direction of the flooding water from the supply canal as it flows slowly towards the opposite end of the field, which is divided into parallel strips by building borders on the edges and intermediate low levees. The surface between levees is transversely level, so that the advancing sheet of water covers the entire width of the strip, but longitudinally has a slight and uniform slope that allows the even movement of the water sheet. Slopes should preferably vary between 0.2 and 0.4 % although the method has been used for a wider range of slopes.

The width of strips usually varies from 9 to 18 m and their length from 100 to 400 m. Rather impervious soils, overlaid by compact loams, permit long and broad strips; highly permeable subsoils, sandy and gravelly, are better irrigated using short and narrow strips. Each strip is usually connected to the supply canal by a gate; siphon tubes can advantageously be used when there is enough difference in elevation between the supply canal and the strip.

3.3 Contour check flooding

This method controls the flow of water by dividing the land into areas or checks of 0.5 to 1.5 hectares by means of check levees built along the contour lines of the terrain and cross levees, transversely to the check levees. The land enclosed by the four levees should be levelled. The area of each check depends on the porosity of the soil; in permeable soils, checks should be smaller to ensure their rapid filling which is necessary for uniform water distribution. Levees are usually 0.25 m high and 1.80 m wide at the base. On steep slopes the ground is graded to a series of level terraces; in gently sloping land, the layout can form a regular pattern of square checks.

3.4 Basin flooding

This method is essentially similar to contour check flooding. It is best adapted to soils having moderate-to-slow intake rates and moderate-to-high water-holding capacities, and to smooth, gentle and uniform land slopes where good layouts for basins can be made.

The basin flooding method may be used for irrigating orchards. Under favourable conditions of soil and slope several trees are enclosed by levees to form a basin. Each basin may be filled individually from ditches between alternate rows of trees or from basin to basin in a line.

3.5 Furrow irrigation

This method does not depend on the overall flooding of land, but makes use of both vertical and horizontal percolation. Only from one-fifth to one-half of the whole surface is wetted. The furrow method thus reduces losses by evaporation, hinders the puddling of heavy soils, and allows farming activities almost immediately after irrigation. Nearly all crops planted in rows are suitable for furrow irrigation.

Furrow irrigation is adaptable to great variations in the ground slope. Slopes of 0.5 to 3 % are most suitable; but many types of soil can be watered with furrow slopes of 3 to 6 %. Furrow irrigation has been tried successfully in ground with slopes up to 15 %, but careful attention must be given to the prevention or correction of erosion. In steep ground, furrows are dug following the contour of the ground but with a slope of 0.5 to 3 % to ensure uniformity in water distribution. In this sort of terrain, the supply canal will necessarily be on a steep gradient and will usually require lining. Movable baffles may be used to divert the flow into the furrows. In some situations the supply canal may have to be replaced by a

pipe carrying water under pressure and delivered through valves.

The depth of the furrow depends on the depth of the root zone of the crop concerned, the nature of the soil, and the agricultural equipment used. In ordinarily permeable soils, furrows vary from 0.07 to 0.15 m deep; in soils of low permeability, furrows should be from 0.20 to 0.30 m deep.

Furrow spacing must allow for the lateral growth of the plant, the need for air circulation between plants, and convenience in cultivation and harvesting. For ordinary crops of low to medium height, furrow spacing ranges from 0.50 to 1.00 m. In orchards, furrows may be spaced from 0.90 to 1.80 m. When the topsoil has a high capillarity or when the subsoil is impermeable, furrows may be spaced as far as 3.00 to 3.50 m.

The length of the furrow is determined by soil permeability, and is often in the range of 100 to 200 m. Very long furrows cannot be irrigated uniformly since it takes time for the water to reach the lower end, which may thus be under-irrigated while the upper end will be over-irrigated.

Furrows of small cross section are usually described as corrugations.

3.6 Subirrigation

This method consists in applying water beneath the ground surface so that it reaches the root zone by capillary movement. For the successful practice of this method, special topographic and soil conditions such as the following are required: (a) large tracts of low-lying land with a uniform and moderate slope of about 0.2 %; (b) a topsoil of permeable loam or sandy loam which permits free lateral movement of water; (c) a relatively impervious subsoil at a depth of about 1.80 m or more, which prevents the percolation of water to the lower strata; and (d) a groundwater table at a level such that only a small rise will enable the soil of the root zone to be moistened by capillarity.

Subirrigation demands that the fluctuation of the groundwater table should be closely followed by means of piezometers or inspection wells. Accurate control of the water supply is essential to prevent waterlogging and accumulation of salts due to excessive supply and to avoid plant wilting due to water deficit.

Subirrigation can be applied either through a system of deep and narrow ditches (0.60 to 0.90 m x 0.30 m at the base) where the soil is consistent and allows almost vertical sides, or through a perforated or open-jointed pipe system, or through a combination of both. Under favourable conditions, it can be a particularly efficient method of water application.

3.7 Sprinkler irrigation

This method consists in applying water to the surface of the ground as an even spray. Sprinkler irrigation can be effective where other irrigation methods are impractical or uneconomical. It is indicated in situations where the land topography is so irregular or hilly that levelling would be too costly, where the ground is too steep or easily erodable, where the cover of fertile soil is too shallow to allow its proper grading, where excessively porous soil does not hold water at the root zone, or where the supply of water is inadequate for efficient and even distribution.

Turbid waters are objectionable for sprinkler irrigation because the abrasive action of silt accelerates the wear of pump propellers, nozzle orifices, bearings and hinges, and debris can obstruct the delivery of water by clogging the sprinkler nozzles. Where the use of turbid waters is unavoidable, appropriate treatment by screening and by sedimentation must be provided. Canal water, when used for sprinkler irrigation, must be diverted to shallow tanks or boxes for a period of settlement before being pumped. It must always be borne in mind that such installations as grit chambers, sedimentation tanks, detritus basins, distribution boxes or pump sumps are potential sites of mosquito breeding which may very easily turn into active

foci of mosquito production. These installations should be examined once a week, and should be drained and dried for a day or so, or treated with larvicides whenever mosquito larvae are present.

3.7.1 Mechanized sprinkler irrigation

One of the earlier types of mechanized sprinkler was the rotating boom with a diameter of 40 to 80 m and an effective watered diameter of up to 180 m (see Fig. IIIB-2). This was either moved by tractor or self-propelled. A later development was the centre-pivot sprinkler which has nozzles mounted along a lateral of up to 700 m radius and is supported on a series of wheeled, power-driven towers at intervals throughout its length as it rotates to water a circular area of some 160 hectares.

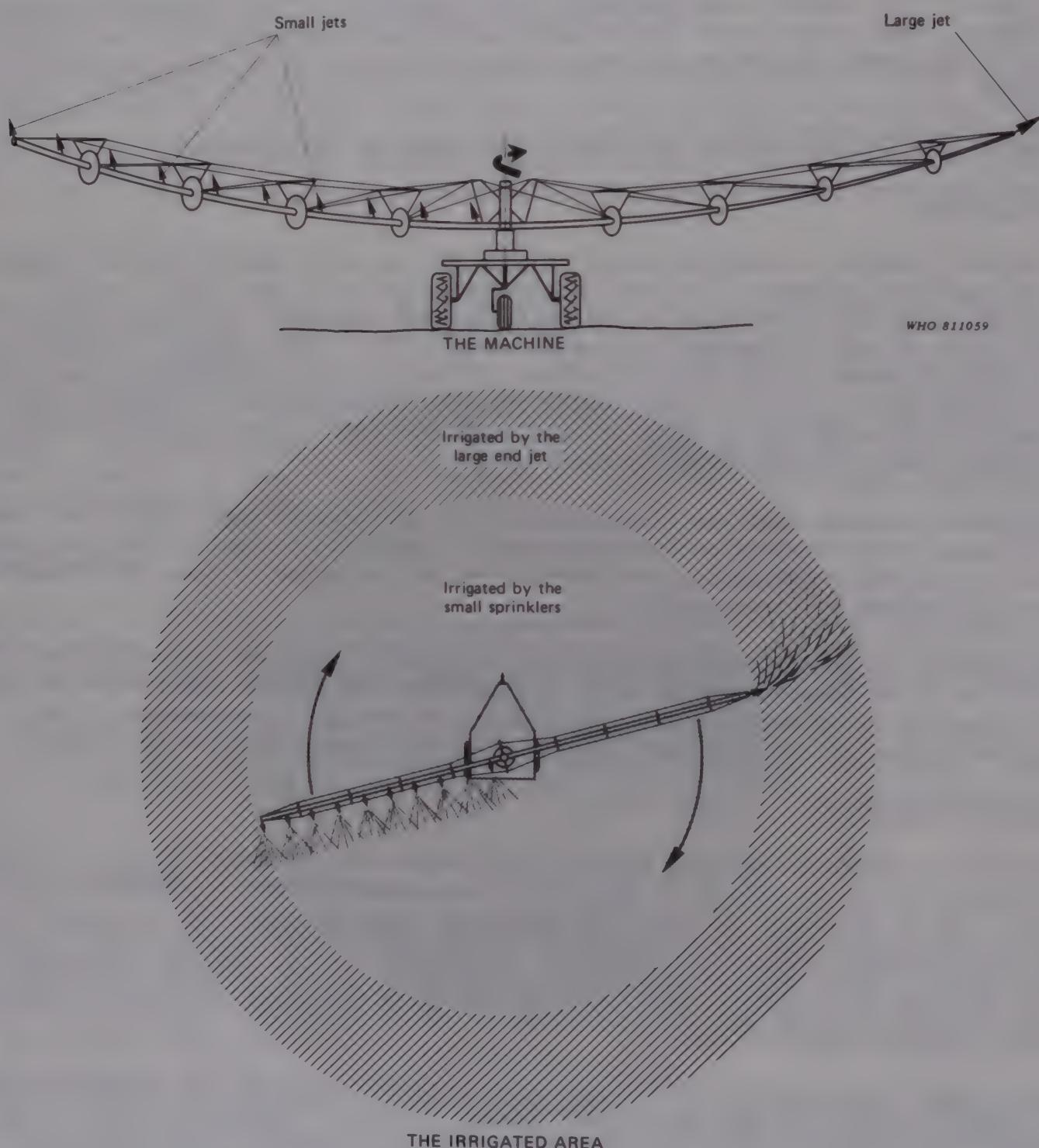


Fig. IIIB-2. Rotating-boom sprinkler.

Other variations include the lateral line or side-move multi-sprinkler system which consists of a long sprinkler line, as with the centre pivot model, but supply is from a flexible hose or channel at one end of the line which advances at a constant rate across the land on self-propelled towers (see Fig. IIIB-3).

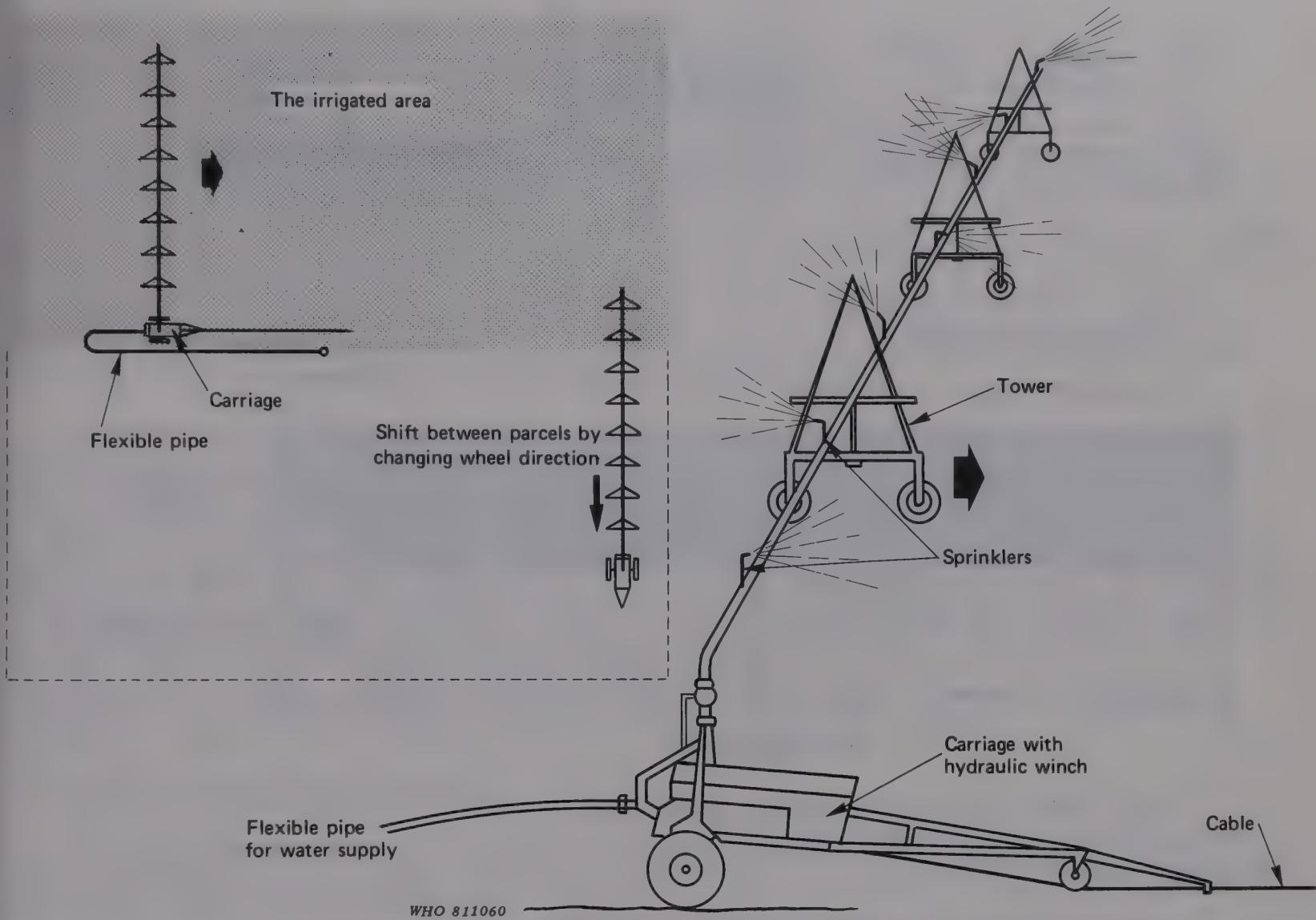


Fig. IIIB-3. Lateral-line sprinkler.

The "big gun" is a single sprinkler system and can be either skid or wheel-mounted and tractor towed, or self-propelled and mounted on a wheeled cart (see Fig. IIIB-4).

These systems offer the advantage of improved water control as regards quantity and timing and, where their use is suited to the type of agriculture, they can therefore be expected to reduce the risk of irregular application and associated mosquito breeding. They can also be used for the application of pesticides with the irrigation water. Even so, they do not eliminate all mosquito breeding problems.

Water supply may still be from an open source, with the risks described for impoundments and channels. The watered area may extend beyond the cultivated area, especially for large circular pattern sprinklers influenced by wind distortion. This can result in standing pools of water on impervious land, on roads, or in drainage channels. The use of wheels or skids

introduces the problem of compaction of the soil in the track of the sprinkler, with a tendency for water to collect in the ruts and provide mosquito breeding sites.

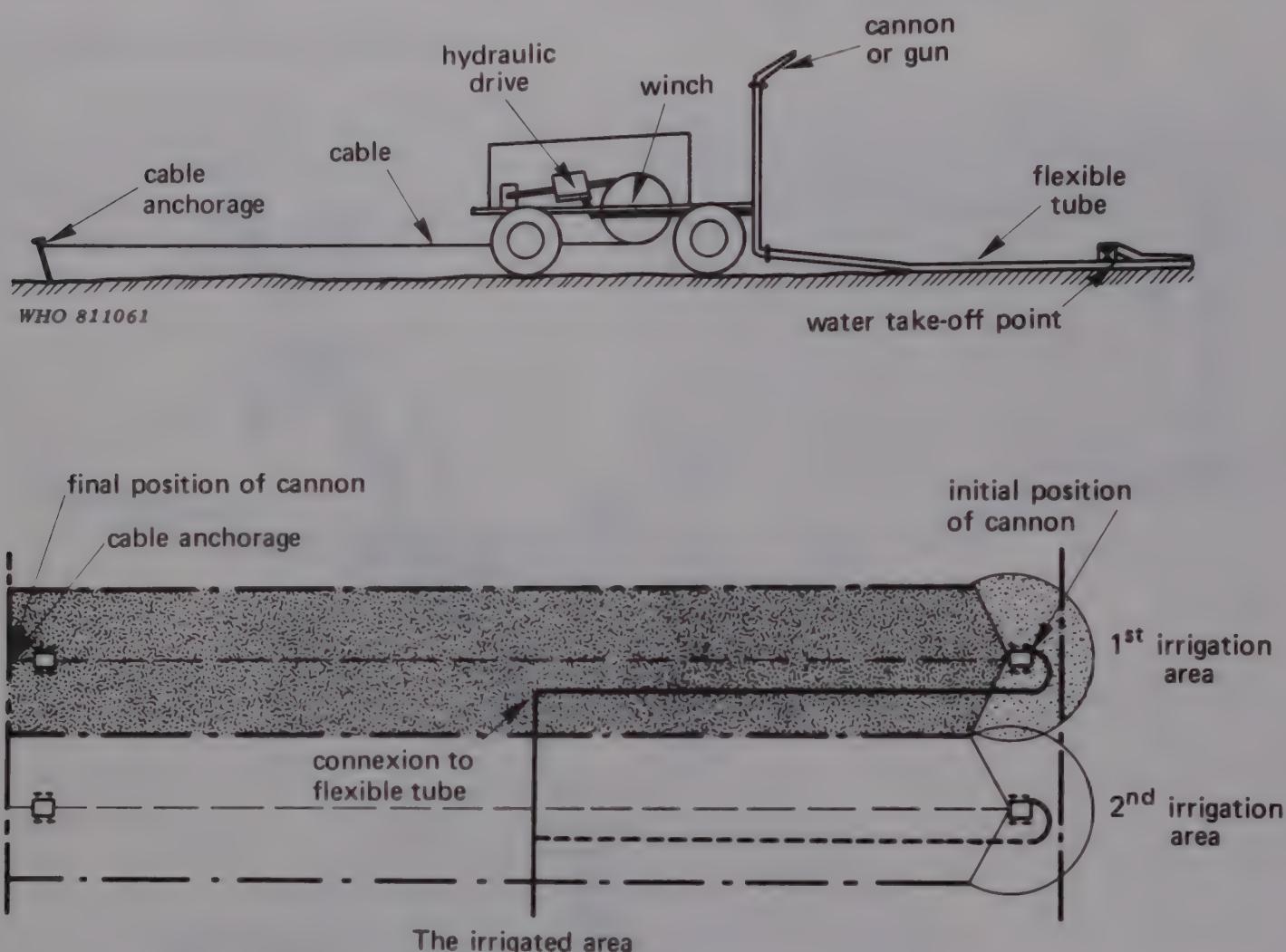


Fig. IIIB-4. Big gun sprinkler, self-towed by cable.

3.7.2 Localized sprinkler (trickle or drip) irrigation

Probably the safest method of irrigation from the viewpoint of mosquito control is the localized system, usually referred to as "trickle" or "drip" irrigation. It consists of a low pressure supply piped directly to the crop, with "emitters" through which water is delivered adjacent to the plant. The system is generally used for row crops and for individual bushes or trees. The emitters may take the form of small orifices in the walls of the plastic supply lines or of calibrated valves mounted on the lines. In all cases, the rate of discharge is adjusted to supply the crop without extensive wetting of the surrounding land and with no standing water. The method has therefore few disadvantages in relation to mosquito breeding when used in the appropriate circumstances.

However, there are technical and economic drawbacks to its use in agriculture. It requires a clean water supply, free from solid and organic matter which may block the emitters; it is not suitable on heavy soils where local ponding may occur; and it is not recommended where crop growth makes access to and inspection of the system difficult or where there is a risk of damage during cultivation and harvesting; the system is expensive and generally is suitable only where high-value vegetable and fruit crops justify the investment.

In arid areas the use of localized irrigation, although well suited to crop production, may cause an increase in soil salinity in the root zone of the plant. This must be corrected by periodic leaching of the soil with a higher discharge method of water application,

probably by surface supply. Such water application has the same implications for mosquito breeding as an equivalent method of surface irrigation, and similar control measures are called for.

4. Mosquito problems in irrigation systems

4.1 In canals

In open irrigation canals, water that leaves the reservoir, river or pumping station is conveyed along main canals to laterals and finally reaches the distribution ditches that supply one or more cultivated fields.

Mosquito problems are to be expected in the whole canal complex, but the greatest risk is in the minor distribution channels which are more suitable for mosquito production than the larger canals, and whose maintenance is given less attention, particularly when it is no longer the responsibility of the irrigation authority and is put under the care of the users. Where waterflow is sluggish, or where canal banks are eroded or choked with vegetation, or where channel sections are irregular, mosquito breeding is a real or potential danger. General experience demonstrates that the smaller the canal, the greater the chance of mosquito multiplication; this also applies to the snail host of schistosomiasis.

Any damage to the channel resulting from heavy storms and flooding, from heavy machinery, cattle crossing, etc. will alter the canal shape and produce water pools where mosquitos will breed. Courses with twists and sharp bends are liable to erosion and silting, resulting in the formation of pockets of quiet water equally suitable for mosquito breeding. Bank erosion may be accelerated by turbulence and whirlpool action in places where there is a change in the water velocity such as occurs downstream of culverts, bridges, chutes and drops, at diversions, and at the outlet of desilting basins. Such erosion widens the canal cross-section, retarding the waterflow and creating conditions suitable for mosquito breeding. Wherever there is a change or obstruction in the canal that causes an alteration of water velocity, the cross-section should be protected against the resulting scouring action. In view of the dangers attendant on erosion, the advantages offered by canal lining are obvious.

4.2 On the land adjacent to canals

The conveyance canal has to be constructed on the highest ground elevation possible in order to irrigate adjacent land. Therefore, canal banks are often raised using earth obtained from "borrow" pits (see Fig. IIIB-5).

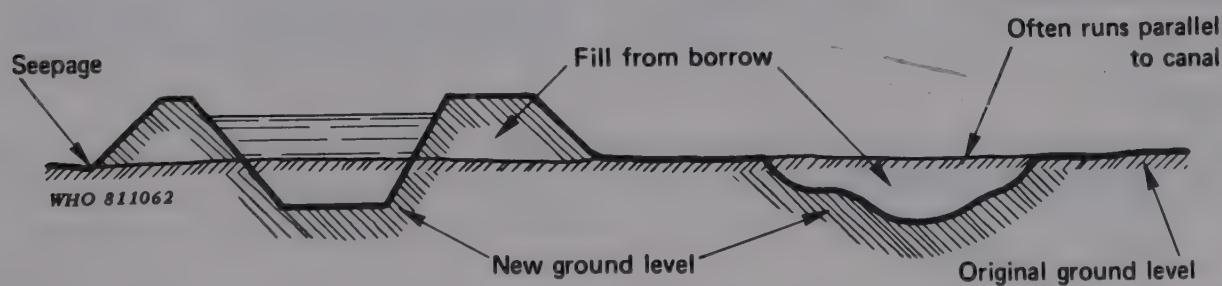


Fig. IIIB-5. A typical conveyance canal section

1006

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Water from the canal is continuously seeping through to the adjacent ground. Except in the case where there is an intentional supply through a planned subirrigation system, this seepage represents an uncontrolled flow in excess of measured deliveries for irrigation, and may raise the groundwater table to a level where it reaches the surface in natural or artificial depressions of the land. These pools, formed on the strips adjacent to the canal, are suitable sites for mosquito breeding. Pools can also be produced by uncontrolled water conveyance and distribution with consequent spillage over the banks and inundation of the land. Pools that may remain for the ten days or so that are required for the egg to develop into an adult mosquito must be filled or drained.

"Borrow" pits are among the most likely spots for mosquito production. Earth for the construction of dams, dikes, canals or roads should be "borrowed" from places where the resulting excavation will not create mosquito breeding sites. Even the most convenient and economical location for "borrowing", if it entails a risk of mosquito production, may have to be abandoned for one where the risk is less, or else provided with preventive drainage works.

Earth can often be borrowed by stripping land at moderately high elevation, thus lowering its level and bringing it within reach of irrigation. In this way the additional expense of hauling the earth may be economically justified.

4.3 In the cultivated fields

Irrigation methods based on the flooding of land, whether the flooding is controlled or not, always present a risk of mosquito production. Two precautions should be taken in order to reduce this risk: (a) each flood period should not last more than a few days, and after the withdrawal of the water the area should be allowed to remain dry for at least one day; and (b) the border strip, contour check or basin should be frequently levelled and graded to ensure an even and uniform surface that will not produce pools when the flood water is withdrawn.

In uncontrolled or "wild" flooding, these two precautions are not applicable, and this method must be recognized as presenting a risk to human health.

The importance for mosquito control of the rapid and thorough removal of water from irrigated fields and of the drying period cannot be overstressed. Unless the drying period is sufficiently prolonged to kill mosquito larvae, the interruption in the delivery of irrigation water will be of no avail. The only way to accomplish the rapid withdrawal of water required before drying the land is by the provision of properly planned drainage.

Though furrow irrigation offers less opportunities for mosquito breeding than flood irrigation, the relatively safe methods from the viewpoint of mosquito production are localized sprinkler (trickle or drip) irrigation, mechanized sprinkler irrigation, and sub-irrigation. It must be noted that even these methods can create a hazard if they are not properly operated.

5. Design of irrigation systems

5.1 General remarks on design

The design of irrigation systems requires a detailed and often specialized knowledge of site conditions and the use of complicated techniques. The subject is beyond the scope of this manual and only general remarks are outlined here for the understanding of the vector control worker.

The subject of water storage is dealt with in subchapter IIIA (Impoundments), but not all irrigation schemes depend on such stored water. Many use river water without impoundment. The river water is diverted directly to the main canal by a side off-take, a pumping station, or a diversion weir built across the river which at the same time ensures a minimum head of water at the diversion point. For the design of such a system it is essential to have a full picture of the pattern of streamflow and its seasonal variations over a long period of record.

The design of an irrigation system is governed by:

(a) The amount of water available to ensure proper irrigation, which in turn determines the maximum area that can be irrigated for each particular crop or combination of crops.

(b) The consumptive use of water, that is, the quantity of water the crop needs in order to grow from the seed to the productive stage, or the plant needs for development and continued production. Consumptive use also includes the losses by transpiration and evaporation that take place in the plant and its adjacent space. It is a particular characteristic of each crop, and is closely related to climatic factors. To provide an indication of the order of magnitude of the water requirement, Table IIIB-1 lists figures for different crops in areas around Hyderabad, India.

TABLE IIIB-1. Water requirements for different crops

(From: FAO/UNESCO. Irrigation, drainage and salinity. London, 1973, p.235).

Crop	Growing season (number of days)	Total water requirement*		Mean daily water requirement	
		m ³ /ha	inches	m ³ /ha	inches
Barley	88	3600	14.1	41	0.16
Chilli	202	9850	38.8	48	0.19
Cotton	202	10700	42.2	53	0.21
Groundnuts	124	6600	26.1	53	0.21
Jowar (<u>sorghum vulgare</u>)	114	6500	25.7	58	0.23
Linseed	88	3200	12.7	35	0.14
Maize	100	4550	17.8	46	0.18
Mustard	88	2700	10.6	30	0.12
Oats	88	3700	14.4	41	0.16
Peas	88	3000	12.0	35	0.14
Potatoes	88	6800	26.7	76	0.30
Ragi	127	7600	29.8	58	0.23
Rice	98	10600	41.7	109	0.43
Sugar Cane	365	24000	95.0	66	0.26
Tobacco	132	10000	39.2	76	0.30
Wheat	88	3750	14.8	43	0.17

* Includes water lost in transpiration and by evaporation and seepage. The results are applicable to areas around Hyderabad, India.

(c) The characteristics of the soil. The depth, permeability, moisture content and chemical quality of the soil, its capacity to retain moisture, and the water table level all influence the amount of additional water to be supplied to satisfy the demand for consumptive use and to prevent a build-up of salts within the crop root zone.

(d) The climate, and particularly the precipitation, temperature, air humidity and wind speed during the cultivation season are factors determining consumptive use.

(e) The topography of the land which is generally a decisive element in the design of the irrigation system.

Based on the above considerations, the engineer will decide the method of irrigation to be adopted, the general layout of the scheme, the type of conveyance preferred, etc. He will then proceed with the detailed design of the canals, pumping stations if required, roads, bridges and other auxiliary structures. The final selection between possible alternatives will

depend on their technical advantages and also on their relative economy. The proposed scheme must be financially viable and economically justifiable.

For mosquito control, there are certain special aspects which need to be considered in the design of an irrigation scheme; engineers have seldom given them sufficient attention in the past, primarily because they did not properly understand the implications. These special considerations are discussed below.

5.2 Special considerations for mosquito control

From the discussion of mosquito problems in irrigation systems (section 4 above) it is clear that mosquito breeding is associated with poor canal conditions, seepage pools along canals, and accumulation of water for prolonged periods on irrigated land. Major methods to prevent and control these situations, which should be given serious consideration by the engineer, include:

- (a) use of a safer irrigation method, such as mechanized or localized sprinkler irrigation, if technically feasible and economically justified;
- (b) use of closed conduits instead of open canals for water conveyance;
- (c) lining of canals;
- (d) good alignment of canals and avoidance of sharp curves;
- (e) effective canal maintenance to ensure that the canals are in good shape and generally free from vegetation and silting at all times;
- (f) intermittent irrigation and periodical drying of canals and fields;
- (g) canal flushing;
- (h) proper forming and grading of the land to be irrigated; and
- (i) good irrigation practices with suitable control to avoid over-irrigation and water accumulation on irrigated land.

Canal lining (item (c) above) and curves in canals (item (d)) are dealt with in detail in sections 6 and 7 below, while land grading (item (h)) is the subject of subchapter IIIF. To facilitate drying of canals and fields (item (f)) and canal flushing (item (g)), it is necessary to install gates and siphons at suitable locations in the canal system; some remarks on this topic are included in section 8 below. Canal flushing as an operation is a manipulative measure and is dealt with in Chapter IV. As water velocity in the canal is usually considered a factor influencing mosquito breeding, the method of calculating velocity in open channels (Manning's formula) and the limitations in velocity manipulation are explained in section 4.2 of Chapter VII.

It is to be noted that good engineering practices in the design, operation and maintenance of irrigation schemes are compatible with mosquito control requirements. The rejection of a better alternative, which is also safer for mosquito control, e.g., the use of closed conduits or lining of canals, is normally made on grounds of its higher initial cost. While the difficulty in raising additional funds for construction should not be underrated, the cheapest alternative in terms of initial cost may not be the most economical in the long-run. This fact is often ignored. The economic comparison between unlined and lined canals given in section 6.5 of this chapter and the comparison between several alternative control methods, as given in section 2.4 of Chapter VII, may serve as examples of how a choice should be made.

The importance of an effective maintenance programme (item (e) above) cannot be over-emphasized. To keep the canals and auxiliary structures in good shape is good engineering

practice and is at the same time beneficial to mosquito control. Such a programme should be envisaged during the design phase of the scheme, and should be adequately budgeted for, appropriately organized, and properly carried out once the scheme is put into operation. Fig. IIIB-6 illustrates some of the good and bad features often found in irrigation systems.

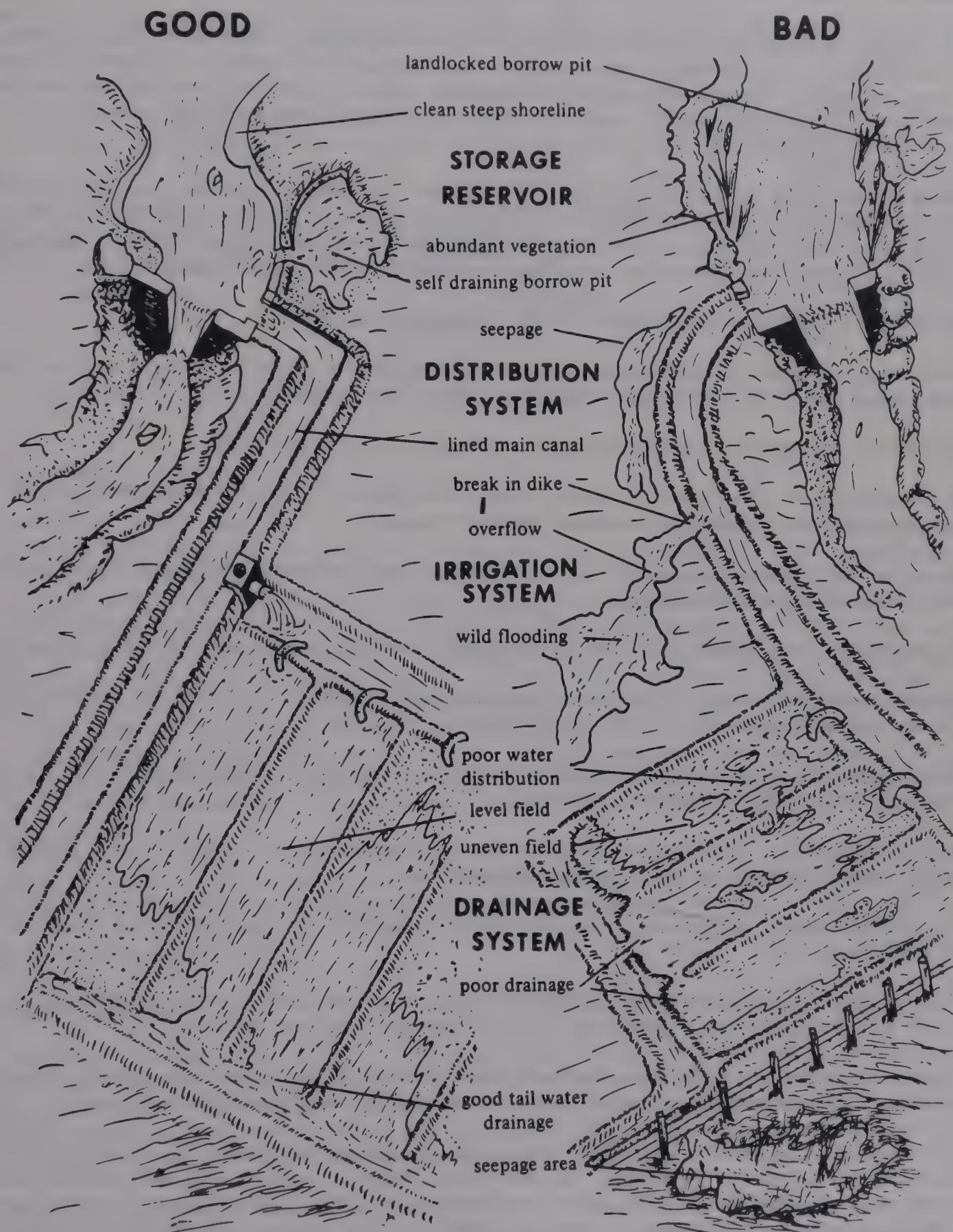


Fig. IIIB-6. Good and bad features often found in irrigation systems.
(From: Mulhern, T.D. (ed.). A training manual for California mosquito control agencies. Visalia, CA, California Mosquito Control Association, 1980, Fig. 9.3).

6. Canal lining

In irrigation systems, water losses can be so great under ordinary operating conditions that only about one-third of the water diverted at the intake of the system is actually delivered to the root zone. The other two-thirds are lost through low efficiency in conveyance and in application, and through deep percolation.

Both application and conveyance efficiencies can be greatly improved. Water losses due to poor application can be reduced by avoiding over-irrigation leading to excess drainage and percolation, by skilful canal management to regulate proper water delivery and by good on-farm practices. To prevent losses due to seepage from canals and laterals, watertight conveyance structures are needed.

Closed underground conduits have many advantages over open channels, and in a number of countries much use has been made of buried plastic or concrete pipes, particularly for small water discharges where silting is not a major problem, but canal lining remains the most commonly used measure for preventing excessive seepage and for other reasons.

The benefits resulting from canal lining include:

- (a) the saving of water by decreased seepage and conveyance losses; this is of particular importance where water is scarce and distant or has to be pumped;
- (b) the protection against deformation and breakage of the canal banks;
- (c) the prevention or reduction of canal scour, silt deposition and weed growth, thus reducing the need for frequent and expensive maintenance;
- (d) the saving of land for cultivation by using narrower channels and fewer drainage ditches, thus also reducing drainage problems;
- (e) the saving in cost resulting from the reduced sizes of canals and auxiliary structures;
- (f) increased crop production by preventing waterlogging of the soil due to seepage and possible salt accumulation at the plant root zone;
- (g) greater command of land resulting from flatter gradients of supply canals, or alternatively the possibility of shorter channels.

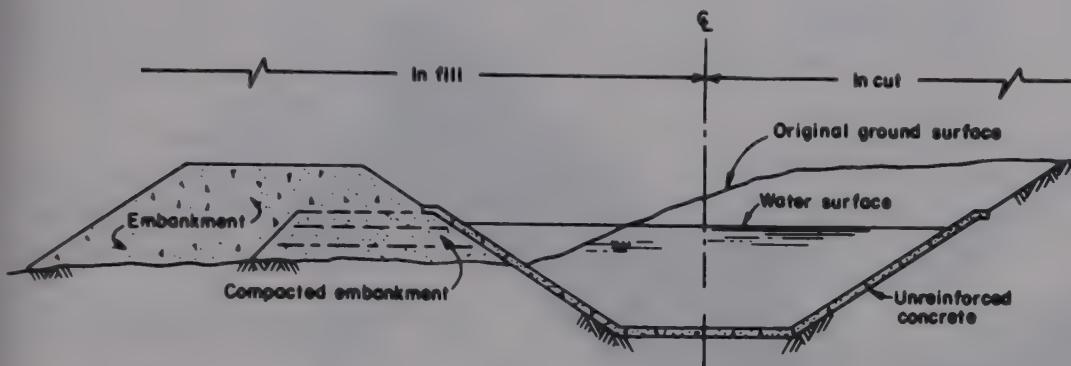
From the viewpoint of mosquito control, the main advantages of canal lining (especially lining with a hard surface or an exposed membrane) are:

- (a) it increases water velocities, thus preventing stagnant or sluggish water that favours mosquito breeding;
- (b) it eliminates rooted growth when properly maintained and facilitates removal of floating weeds, thus depriving mosquito eggs and larvae of protection and shelter;
- (c) as seepage is less, it reduces the need for drainage; drains, which always represent an active or potential danger of mosquito production, can be fewer and further apart.

The repeatedly expressed view that lined canals are too expensive is usually based on considerations of initial cost alone. An analysis, properly carried out and taking into full account the various benefits listed above, may well prove that canal lining is more economical (see example in section 6.5 below). Even in terms of initial costs, lined canals should be rather competitive in new irrigation systems when the construction work is incorporated in the original design and is offset by reduced excavation and other costs. Canal cross-sections and auxiliary structures can in many cases be made smaller since the carrying capacities required are reduced (seepage loss being less) and higher flow velocities may be possible.

In existing canal systems, lining will be an additional cost; consideration should then be given to possible advantages from their relocation, as it may be less expensive to dig a new ditch than to prepare an old one for lining. In that case, provision must be made for treatment of the old ditch by filling, draining, or otherwise modifying it so that it does not present a mosquito problem.

Canal linings are of several different types. These are discussed in the following sections.



(Adapted from:
McJunkin, F.E.
Water, engineers,
development, and
disease in the
tropics, Washington,
DC. United States
Agency for Interna-
tional Development,
1975).

Fig. IIIB-7. Typical section of concrete canal lining.

6.1 Paved or hard surface

The materials most used for this type of lining are Portland cement concrete, asphalt concrete, stone and brick (see Fig. IIIB-7). When properly constructed and maintained, a paved hard surface lining embodies more desirable features than any other type. In addition to controlling seepage, it permits velocities conducive to minimum sedimentation without scouring and affords maximum obstruction to weed growth. Furthermore, it is durable and resistant to mechanical impact. Portland cement concrete lining can be made *in situ* or can take the form of precast slabs or panels. The latter method is widely applied because it is rapid, simple and requires the minimum of equipment. Asphalt concrete, where properly used, can produce linings comparable in many aspects with those of Portland cement concrete. However, the expected service life may be shorter and the subgrade soil may have to be treated to prevent plants and weeds piercing the lining. The choice between Portland cement and asphalt concrete will depend on price differences and the suitability of local materials for use as aggregates.

Linings of brick and stone masonry are advisable only where the cost of labour is low and where there is abundance of these materials in the locality.

6.2 Membranes (see Fig. IIIB-8).

6.2.1 Exposed membrane

In principle, a lining should be so flexible that it can adapt to small settlements in the subgrade without breaking, cracking, or ceasing to be watertight. At the same time, the lining should be reasonably resistant to deterioration from weathering, changing pressures, and mechanical rubbing or impact. Among the materials that have been tested and shown to meet these requirements, the most satisfactory are:

(a) Prefabricated planks of heavy asphalt sandwiched between two thin layers of asphalt-saturated felts. Channels of uniform cross-section are most suitable for this lining, provided that good alignment is maintained throughout.

(b) Prefabricated asphalt-coated jute sheeting, which is, however, less satisfactory than the thicker asphaltic felt plank type. It deteriorates more rapidly and is less resistant to mechanical damage.

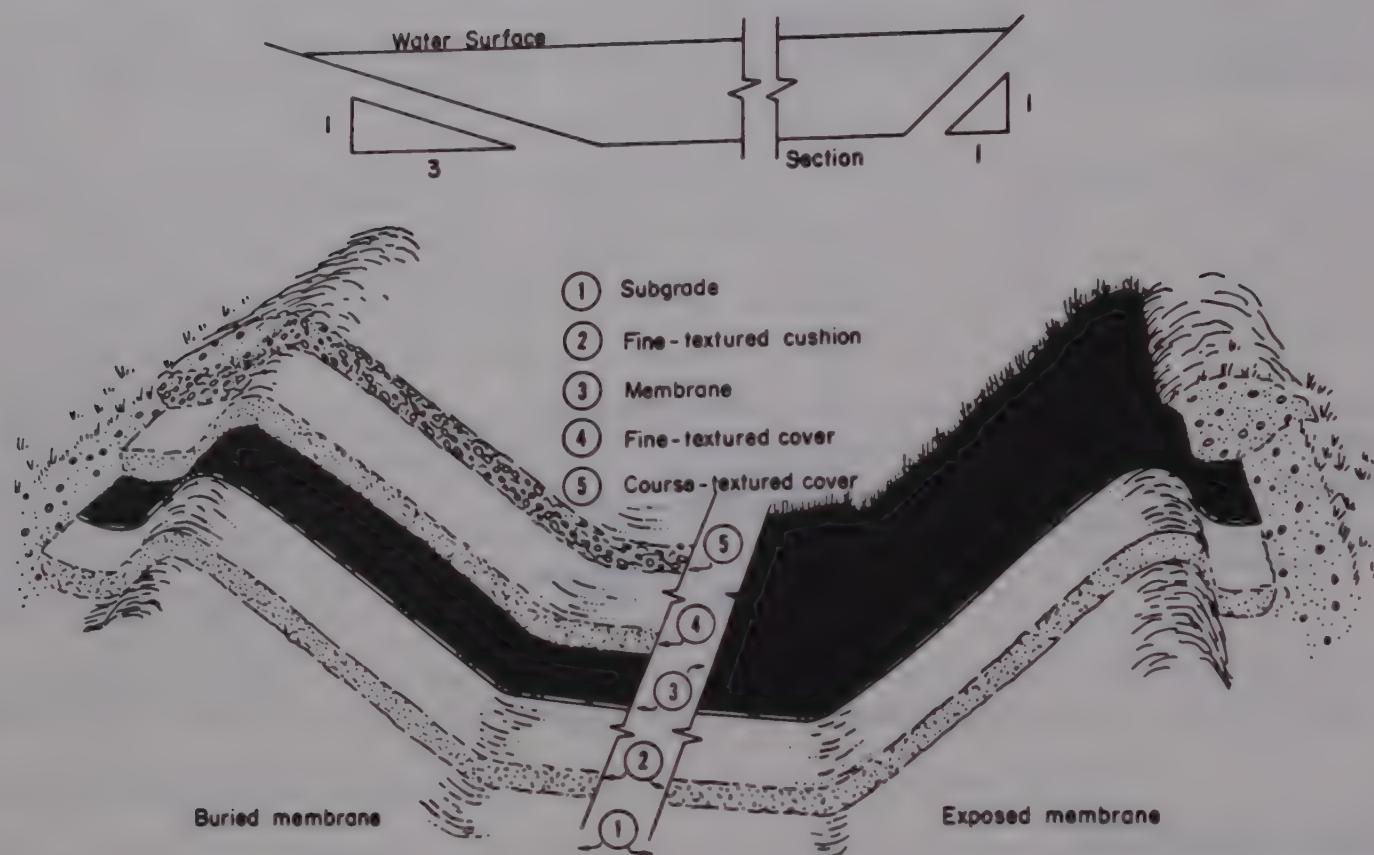


Fig. IIIB-8. Typical section of canal showing two types of membrane.
(Adapted from: McJunkin, F.E. Water, engineers, development, and disease in the tropics, Washington, DC. United States Agency for International Development, 1975).

(c) Butyl rubber sheeting, which is the most satisfactory lining material for exposed membranes, is supplied with or without fabric reinforcing. Thinner nylon-reinforced sheeting is also available. Butyl linings are watertight and age very slowly.

The exposed membrane linings have about the same roughness coefficient as concrete linings. The maximum permissible velocity is estimated to be 0.9 m/s. This type of lining requires more care in removing sediment than the hard-surface type. These linings are also subject to a degree of damage by livestock and should be protected from heavy animal traffic. If silt deposits remain for extended periods, weeds will grow in the exposed and shallow portions and may puncture the lining, particularly if it is of the asphalt type. Subgrade sterilization prior to installation will protect against vegetation erupting through the lining.

6.2.2 Covered membrane

This type of lining is very effective in controlling seepage and, because it is less expensive than other linings, its use has extended in recent years. The membrane may consist of any watertight material that has a long life in the soil.

(a) Earth membrane. Bentonite or other impervious soils are used in this type. Very little preparation of the subgrade is required, but the canal must be shaped to proper alignment and grade.

(b) Covered asphalt membrane. This is a relatively recent development in lining techniques.

It consists of a thin layer of asphalt sprayed on the prepared subgrade of the canal, a cover of fine texture earth, and a layer of gravel on top.

(c) Plastic film and rubber sheeting. In this type of covered membrane lining, the asphalt layer is replaced by a film of polyvinyl or polyethylene, or rubber sheeting as used in the exposed membrane lining. Both the film and the sheeting are more nearly watertight and resistant to puncture by vegetation than the asphalt membrane, but sterilization of the subgrade is still considered advisable. Butyl rubber sheeting, which is used for exposed membrane linings, is also suitable for buried membrane lining. However, it is more expensive than the plastic film because it has to be thicker. Nylon-reinforced butyl sheeting, which is particularly suitable where internal stress may develop, must not be less than 0.8 mm thick to afford sufficient protection to the nylon mesh.

In covered membrane linings, the cover materials are almost as erodable as the untreated earth in unlined canals, and the surface has about the same roughness and tolerates the same maximum flow velocity as that of unlined canals. Weeds may grow on the earth cover, reducing the method's effectiveness in mosquito control.

6.3 Compacted earth

Where suitable earth material is available at or near the site of construction, a lining of thick compacted earth may be an economical and effective means of controlling seepage (see Fig. IIIB-9). Gravelly and sandy clays with plasticity indices^a between 21 and 24 are the best soils. Materials with a high index are difficult to work and tend to be unstable. Those with a lower index have less resistance to scour and in cold climates are susceptible to frost damage.

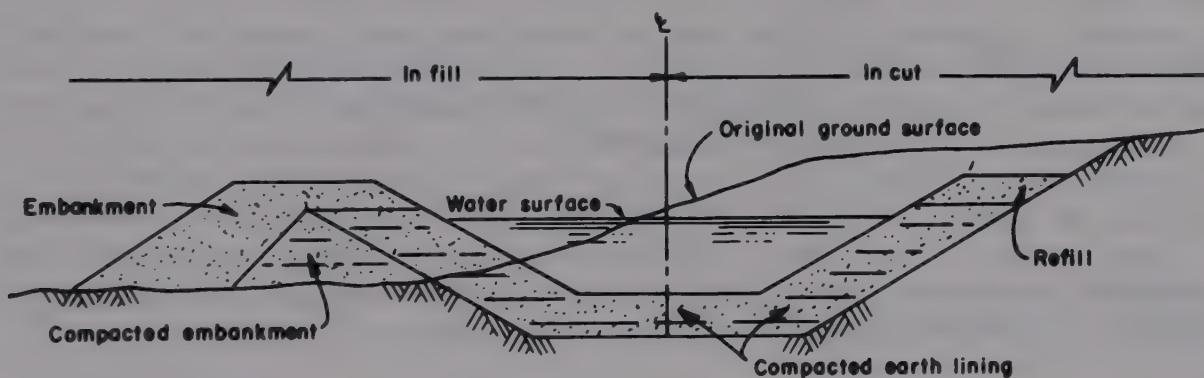


Fig. IIIB-9. Typical section of thick compacted earth lining.
(Adapted from: McJunkin, F.E. Water, engineers, development, and disease in the tropics, Washington, DC. United States Agency for International Development, 1975).

A thick compacted earth lining is constructed by spreading selected earth materials in layers, 0.15 m thick, and compacting each layer with a smooth roller. This material should have a moisture content which will allow maximum compaction. The subgrade of the canal before the lining cover is applied, should be over-excavated to accommodate the thick layer of earth and the side slopes should be such (usually 2:1) that scouring is resisted. The effective thickness of the lining varies from 1.10 m for larger canals to a minimum thickness of 0.3 m for very small canals.

^a Plasticity index = the difference in water content as percentage of dry weight at the liquid limit and plastic limit of a soil.

The reduction of seepage loss depends on the impermeability of the material, which can be improved by blending it with fine-grained clays and silts or by adding asphalt or Portland cement (soil-cement) which also increases resistance to scouring. However, regardless of the water-transmitting characteristics of the earth material, a great improvement is achieved by proper and thorough compaction.

Water velocities in canals with any type of earth lining must not exceed the limit that causes erosion. This permissible limit depends on the nature of the material and is usually less than 0.9 m/s. Even then, scouring may take place in bends and below structures, and a topping of gravel or rock must be laid in such critical areas; the generalized use of this topping will reduce the need for frequent maintenance. Like covered membrane linings, compacted earth linings have about the same smoothness as unlined canals, and hence have no hydraulic advantage over them with respect to carrying capacity. They will not control vegetation growth as effectively as a paved or hard surface lining.

As the volume of earth material to be excavated, conveyed, spread and compacted is large, heavy equipment is unavoidable if compacted earth lining is to be competitive with other types in cost and speed of application.

6.4 Earth and chemical sealants

For a long time it has been known that in natural courses and canals carrying muddy water, leakage, erosion and waterweed growth are reduced. Attempts have been made to imitate this process by sluicing fine-grained material into canals, but the degree of seepage control obtained was too slight to justify the continuation of this practice.

The idea of a waterborne sealant and channel stabilizer was too attractive to be abandoned, but the many materials and methods that have been tested have met with only partial success. Waxes, asphalts, resins, lignins and polymers have been tested as chemical sealants. Prepared in emulsion form and released in the water, they flow down the channel, settle on the perimeter and ultimately percolate into the soil. Trials show, however, that the sealant is held on the surface where it is easily damaged. What is needed is a sealant that penetrates the soil but not deeper than 15 to 20 cm, so that it concentrates where it is needed without being exposed to damage. Claims have been made that sealants have reduced seepage losses by 60 %. Even if this is so, their effectiveness is not long-lasting and they have to be applied at frequent intervals; but if the treatment is inexpensive enough, periodic applications may compensate for short-term effectiveness.

6.5 Service life and comparative costs

Experience has shown that paved or hard surface linings may last indefinitely with the minimum of maintenance. Stone, brick and concrete revetments of large rivers in European cities and of small channels in tropical rural areas, built at the beginning of this century or even earlier, are still serviceable. Therefore a conservative figure for the service life of hard surface linings, for use in estimating depreciation, would be 50 years.

Soil-cement linings are supposed to be still serviceable after 10 years of use. The assumption has been proved correct in cases where cracking, scaling and other surface deteriorations have been immediately repaired.

Membrane linings are more affected by weather factors than other types of linings. In general, the life expectancy of membranes is between 5 and 10 years. Linings that depend on sealants and compacted earth are considered to last even less well than membrane linings.

The comparative cost of different linings was an element in a research project^a carried out in 1970 by the Government of India with FAO assistance. From information produced by this project, it may be concluded that the construction cost per unit length of a lined canal, compared with that of a similar unlined canal, is about 8 to 9 times higher, for brick and concrete linings; about 3.5 to 4.5 times higher, for soil-cement linings; and about 2.5 to 3.5 times higher, for clay and bitumen compaction.

In an FAO publication^b an illustrated example of cost analysis for an unlined and a lined canal of equal water-carrying capacity ($28.3 \text{ m}^3/\text{s}$) is presented. A short resumé follows.

The comparative cross sections of the unlined and the lined canals are shown in Fig. IIIB-10.

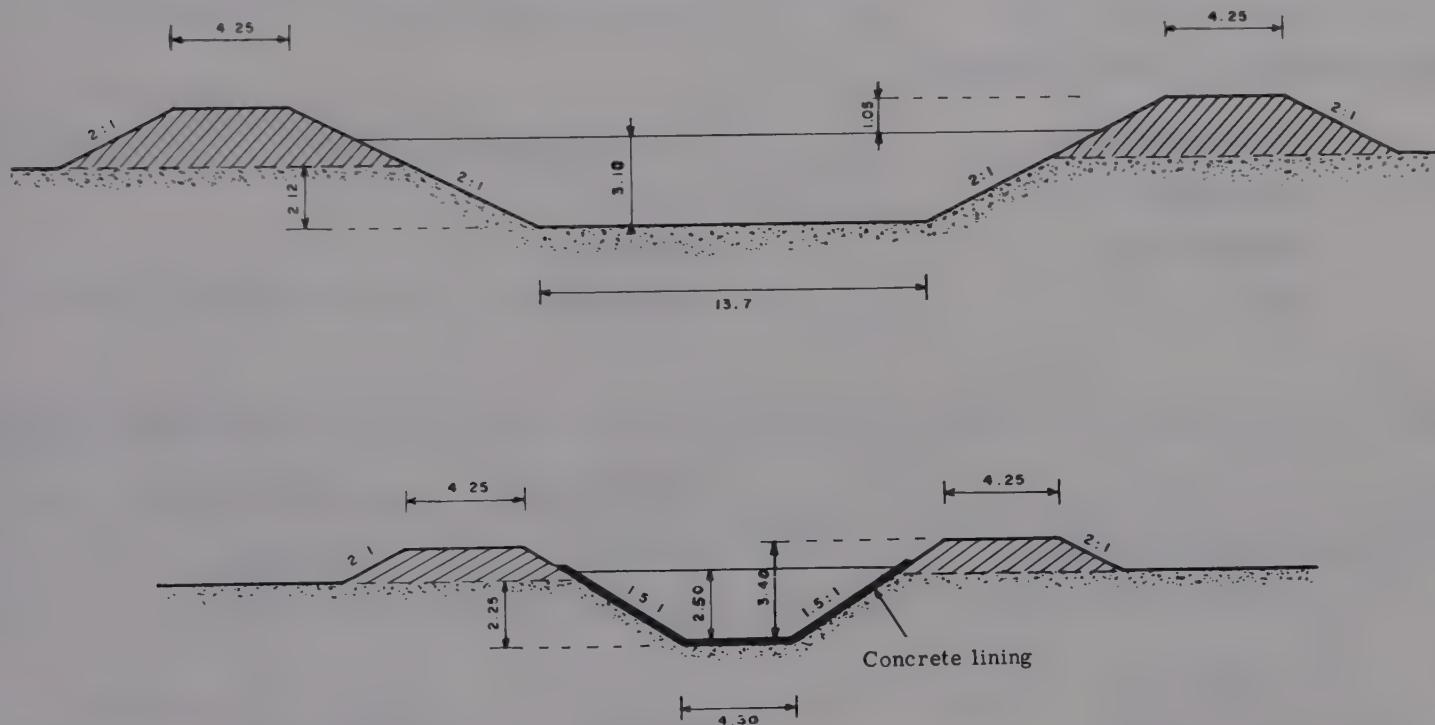


Fig. IIIB-10. Comparative cross sections of an unlined and a concrete-lined canal (in metres). (From: FAO publication^b)

The hydraulics of the two sections are determined according to the following assumptions and criteria:

	Unlined canal	Lined canal
Permissible velocity	0.5 m/s	1.5 m/s
Bank slopes	2:1	1.5:1
Seepage loss	$0.46 \text{ m}^3/\text{m}^2/\text{day}$	$0.015 \text{ m}^3/\text{m}^2/\text{day}$
Coefficient of roughness, n (Manning)	0.0225	0.013
Land area lost	$47 \text{ m}^2/\text{m}$ of canal	$31 \text{ m}^2/\text{m}$ of canal
Annual maintenance cost	\$1.15/m	\$0.50/m

^a Food and Agriculture Organization of the United Nations. Soil survey and soil and water management research and demonstration in the Rajasthan Canal area, India: Investigations in soil and water management. Rome, 1971 (unpublished document AGL:SF/IND 24, Technical Report 2).

^b Kratz, D.B. Irrigation canal lining. Rome, Food and Agriculture Organization of the United Nations, 1977 (Land and Water Development Series, No. 1).

Factors common to the two canals:

Maximum water depth	:	3.10 m
Top width of banks	:	4.25 m
Available slope	:	0.0002
Cost of excavation	:	\$0.65/m ³
Value of water	:	\$0.33/100m ³
Annual interest rate	:	5 %
Annual right-of-way cost	:	\$180/ha
Equivalent time of operations	:	6 months continuous full flow

Data pertinent to the lined canal:

lining material	:	Portland cement concrete lining, unreinforced
thickness	:	7.6 cm
service life	:	40 years
cost	:	\$4.30/m ²

Based on the technical criteria, the hydraulic computations give the following results:

	<u>Unlined canal</u>	<u>Lined canal</u>
Cross-sectional area	62 m ²	20.2 m ²
bed width	13.7 m	4.3 m
water depth	3.1 m	2.5 m
Wetted perimeter	27.5 m	13.2 m
Hydraulic radius	2.26 m	15.3 m
Hydraulic gradient	0.000036	0.000036
Freeboard	1.05 m	0.9 m
Excavation	38.0 m ³ /m	17.3 m ³ /m
Seepage loss	$27.5 \times 0.46 = 12.7 \text{ m}^2/\text{m/day}$	$13.2 \times 0.15 = 0.2 \text{ m}^3/\text{m/day}$
	$12.7 \times 180 = 2300 \text{ m}^3/\text{m/season}$	$0.2 \times 180 = 36 \text{ m}^3/\text{m/season}$

Calculation of the annual cost per metre is given below:

	<u>Unlined canal</u>	<u>Lined canal</u>
(a) Capital cost:		
excavation	38 m ³ at \$0.65	= <u>\$24.70</u>
concrete lining		17.3 m ³ at \$0.65 = 11.25) 15.4 m ² at \$4.30 = 66.22) <u>\$77.47</u>
interest	$\frac{1}{2}(24.7 \times 0.05)$	= \$ 0.62 $\frac{1}{2} (77.47 \times 0.05)$ = \$ 1.93
depreciation of lining		66.22/40 = \$ 1.65
(b) Value of lost water/year	2300 m ³ at \$0.33/100 m ³ = \$ 7.60	36 m ³ at \$0.33/100 m ³ = \$ 0.12
(c) Maintenance		= \$ 0.50
(d) Right-of-way cost	180 x 47/10000 = \$ 0.85 \$10.22	180 x 31/10000 = \$ 0.56 \$ 4.76
Annual saving per metre of lined canal	= \$ 5.46	

7. Curves in canals

Canals with bad alignments rapidly deteriorate through erosion and silting. To reduce the need for channel maintenance, canals should, where possible, have long straight reaches and large radius curves that allow a streamline flow. Table IIIB-2 gives data on curves for canals and Fig. IIIB-11 illustrates the elements referred to in the Table.

Table IIIB-2. Minimum radius of curvature for canals in stable soil without bank protection.

Type of canal and width at water surface	Fall or gradient per cent	ft/mile	Minimum radius m	ft	Degree of curve metric	English
Small	< 0.02	< 3	90	300	13°	19°
< 4.5 m (15 ft)	0.02 to 0.04	3 to 6	120	400	10°	14°
Medium	< 0.02	< 3	150	500	8°	11°
4.5 to 10 m (15 to 35 ft)	0.02 to 0.04	3 to 6	180	600	7°	10°
Large	< 0.02	< 3	180	600	7°	10°
> 10 m (35 ft)	0.02 to 0.04	3 to 6	240	800	5°	7°
			chord	20 m	100 ft	

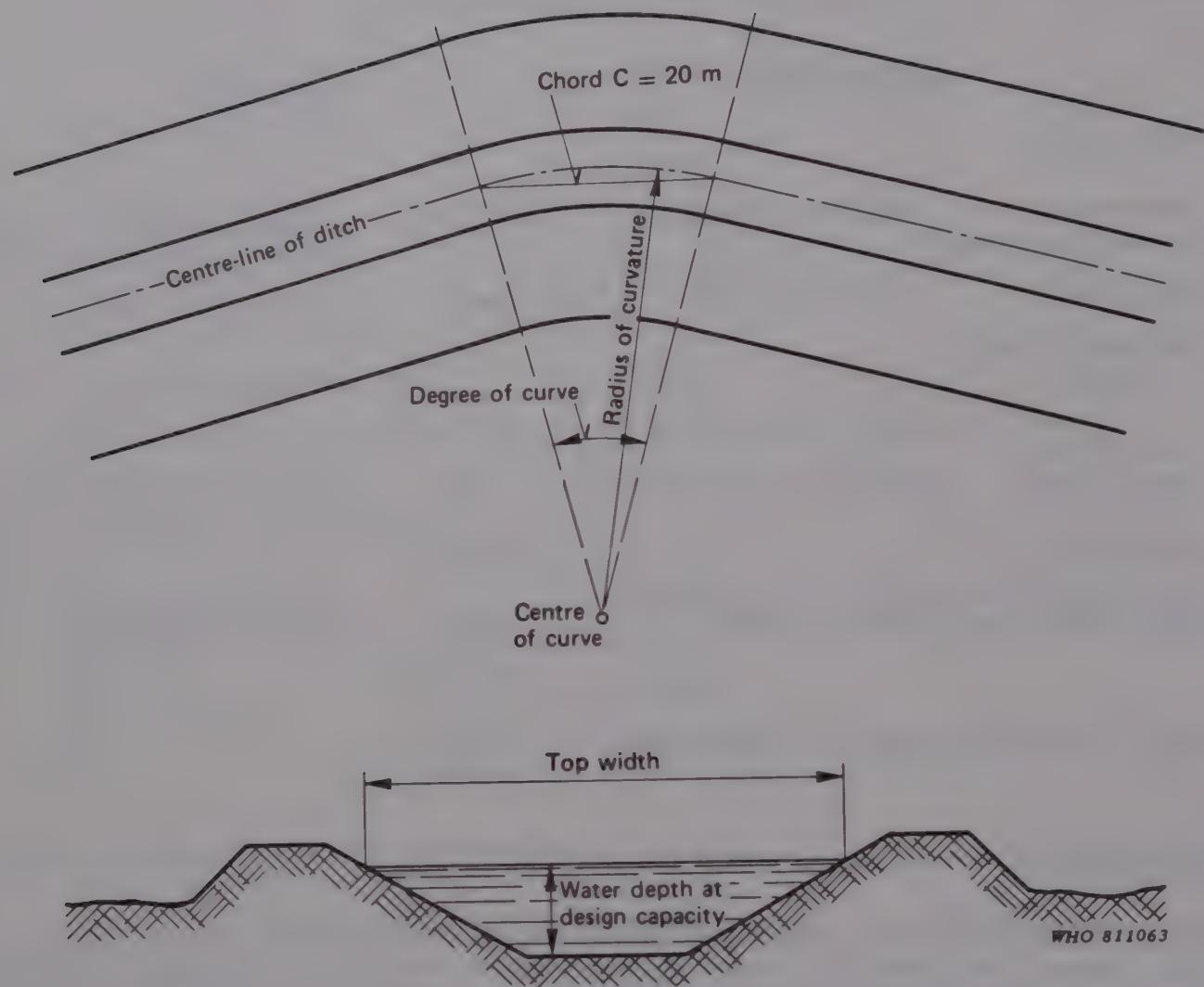


Fig. IIIB-11. Radius of curvature, degree of curve and top width of canals.

8. Gates and siphons

In many places it has been proved that channel flushing and, to a certain extent, channel drying have a good effect on reducing mosquito populations. These measures need certain permanent structures for their proper application (see Chapter IV, section 5, stream flushing).

The normal operation of an irrigation system requires the installation of gates at convenient sites to regulate the distribution of water to the various sectors of the system. These gates are usually located at the head of secondary and tertiary canals. If canal flushing and drying are to be restricted to smaller portions of the system so as to interfere less with operations, the installation of more gates or the construction of weirs provided with self-priming siphons are required. It may not be generally necessary to introduce this practice into the routine operation of the system, but it should be considered when and where an increase in the mosquito population indicates the need for such measures. There will, of course, be situations where the intensive use of irrigation water will make it impracticable to interrupt the flow for the period required for drying mosquito eggs and larvae, even within a small portion of the system.

IIIC. NATURAL STREAMS

Contents

	<u>Page</u>
1. Introduction	65
2. Reinforcement of the banks	65
3. Deepening of a central channel	66
4. Diversion of peak flow through floodways	68
5. Channel straightening	68

1. Introduction

The crooked meandering course of rivers and streams in flood plains results from slow but continuous changes produced by silt deposits while under normal flow, and bank erosion during periods of high flow and occasional flooding. This is a natural phenomenon frequent in rivers and would not be of importance to mosquito control if it were not for the formation of backwater pools, marginal pockets and isolated seepage ponds that are suitable habitats for mosquito breeding. To prevent mosquito production and consequent disease transmission, the channel of natural streams needs to be corrected in those sections where these conditions occur and where the distance to human dwellings is within the flight range of the local mosquito vector (see Annex 1).

2. Reinforcement of the banks

To eliminate backwater pools and marginal pockets, the eroded or fallen stream banks will have to be rebuilt in alignment with the unaltered banks. This work may require the construction of levees which will also give flood protection and prevent the formation of swamps by water overflowing to low-lying areas (see Fig. IIIC-1).

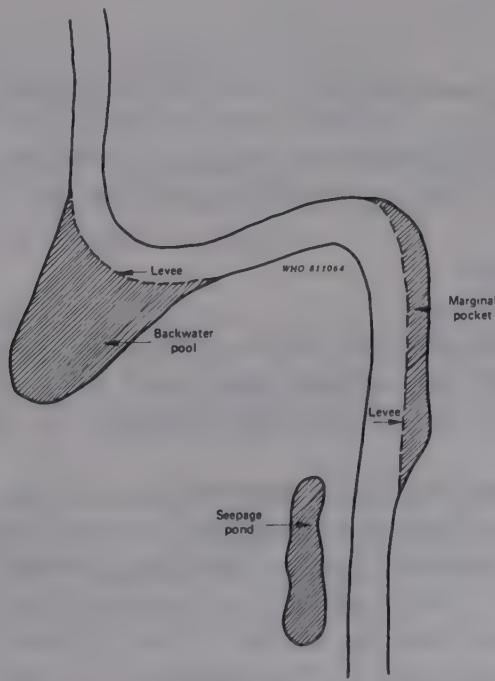


Fig. IIIC-1. Locations of mosquito breeding in rivers and other natural streams.

Where stones are abundant, the levees can be advantageously replaced with barriers made of loose rocks, cobbles, etc., encased within wire mesh. These casings, known as gabions, are made by setting on the site a long and relatively narrow strip of wire-mesh with the edges upturned to form a long, rectangular basket that is filled with stones. Wire cross-ties keep the vertical sides in shape and prevent deformation caused by the weight of the stones. Another strip of wire mesh is tied on the top, when the basket is full, thus completing the casing.

The galvanized steel wire mesh commonly used for these gabions is 3.2 to 6.3 mm in diameter with 7.5 to 10 cm spacing. The usual shape of the casing is prismatic from 1 to 2 m wide, 1 to 1.5 m high, and 10 m or more long. The gabions are set in a single or double line to form the barrier. They are generally laid against the natural banks of the river but they can also be designed as a gravity structure to stand free in those sections where the banks are completely destroyed. Fig. IIIC-2 illustrates the use of gabions.

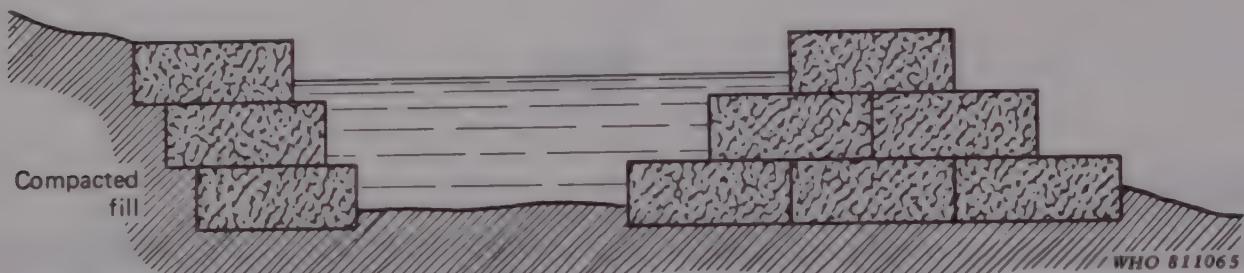


Fig. IIIC-2. Gabions placed to protect a river bank and to replace a demolished embankment.

The gabion can stand the water force as well as a solid levee. It permits the passage of water and allows the settling of coarse sediment that fills the spaces between the rocks. Sediment that passes through a new gabion levee partly settles against the outer face and gradually builds up a natural fill on that side. The best time for erecting gabions is immediately after the flood season when the water has gone back to its normal flow. Then there will be a long time during which sediment will accumulate as the slower but still heavily silted water passes through the gabion wall. When the next flooding period occurs, much of the sediment will be sufficiently consolidated to withstand the action of the peak flow.

One of the major advantages of gabions over solid revetments, levees or retaining walls is their flexibility. They can adapt better than other types of embankment or dike to subsidence of the ground and resulting distortion without cracking, tumbling or crumbling. The repair and replacement of gabions can be readily carried out by local labourers.

3. Deepening of a central channel

Where the silt deposit on the stream bed is irregular, mainly as a result of an obstacle in the course (such as a rock outcrop, gravel and sand bar, or accumulation of debris), the hydraulic characteristics of the channel can be improved by correcting the gradient.

In meandering courses exposed to heavy torrential flows, it often happens that the rushing water scours the concave side of a bend and a sand bank is built up on the convex side. Thus the line of maximum channel depth does not coincide with the centre line, but moves from one side to the other. This erratic course of the greatest depth line, besides extending the length of the stream during normal flow, distorts the shape of the cross-section and reduces the water carrying capacity of the channel. Fig. IIIC-3 illustrates this feature.

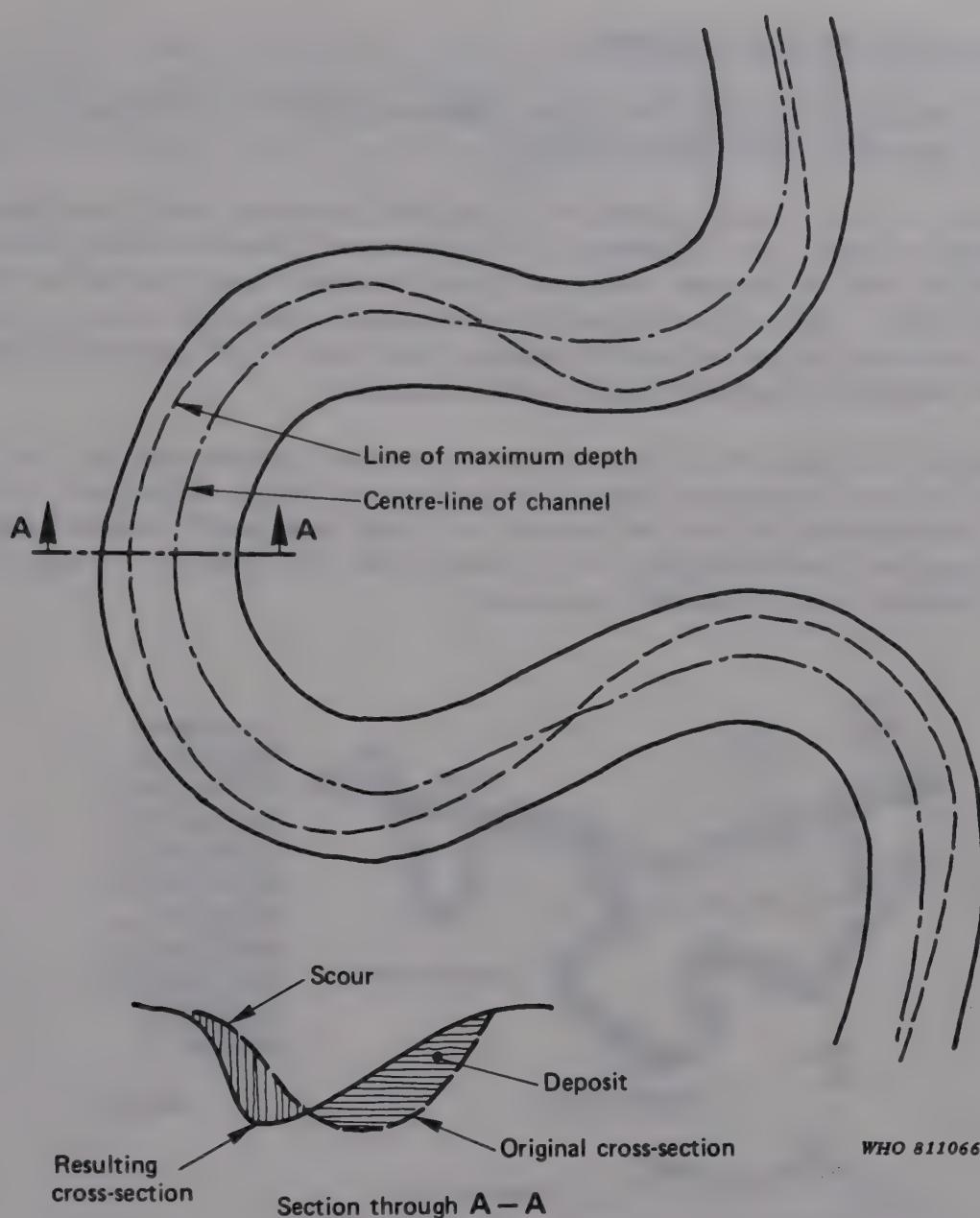


Fig. IIIC-3. Distortion of the channel bed of a meandering stream caused by torrential flows.

The realignment of the maximum depth line and the straightening of the gradient can be carried out by dredging the bed material using mechanical dredgers, power shovels, dragline bucket excavators, or hydraulic dredgers of the sand-pump type.

If the dredging of the channel is combined with the strengthening of the banks, whether by levees or gabions, the dredged material can be disposed of by building up the levees or piling it against the landside face of the gabions.

In the modification of channel characteristics by regrading or straightening (see section 5 below), there is a need to maintain an energy balance, usually by incorporating control structures in the form of weirs or drops. Otherwise, scour and deposit of sediment will reinstate the original conditions, or cause similar effects in adjacent reaches.

Streams with periods of very low flow present conditions similar to those of drainage ditches as regards mosquito production. Mosquito breeding in stretches of the stream in the vicinity of human habitations can be reduced or prevented by lining such stretches with concrete inverts, as described in subchapter IIID, section 6.

4. Diversion of peak flow through floodways

Developed areas can be protected from flood damage, without modifying the natural river courses, by providing an additional water course.

At a certain point of the course, preferably before reaching the flood plain, an auxiliary channel is constructed to serve as a floodway. This channel receives only that part of the flood water which spills over a lateral weir into the floodway when the water level in the river is sufficiently high. Water in the auxiliary channel flows directly to a point of the river downstream of the area to be protected against the flood. The channel should have ample capacity to carry the maximum flood discharge rate expected.

The risk of mosquito production in the floodway channel arises during the dry season when it is out of service but may intercept natural tributary drainage throughout its course. The total flow of these tributaries may not be enough to flush out small depressions in the channel. In this situation the lining of the floodway bed with concrete inverts is indicated. Fig. IIIC-4 shows an example of a floodway channel.

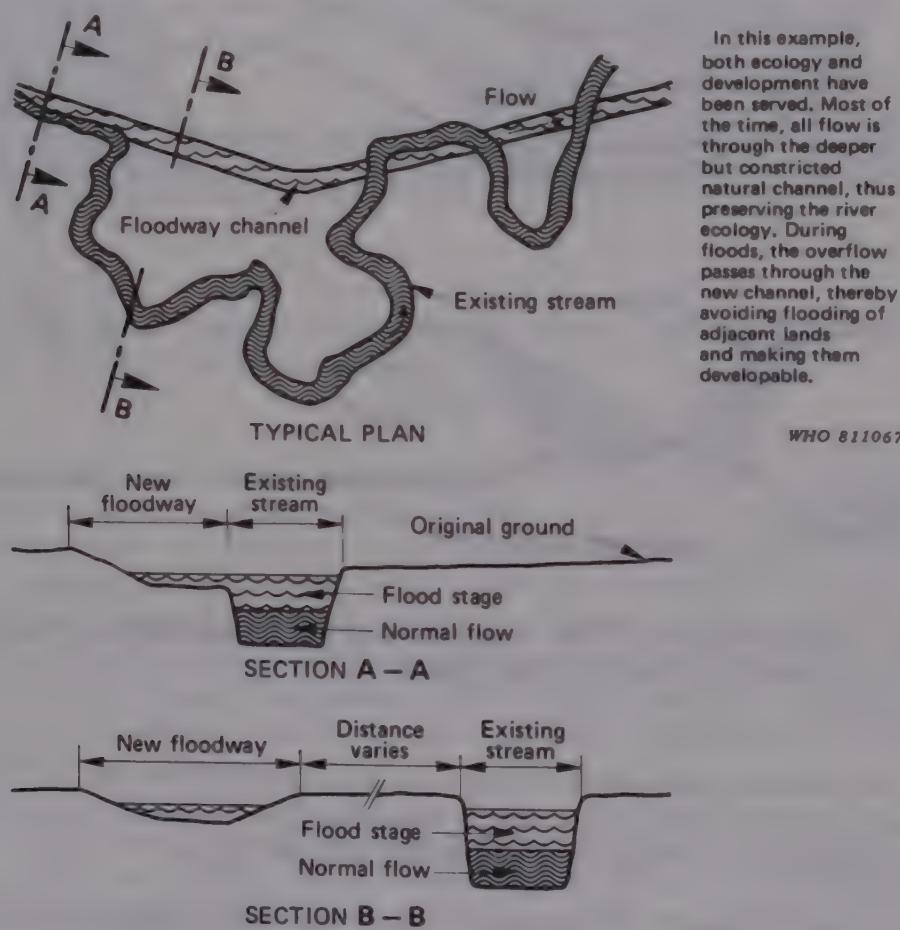


Fig. IIIC-4. Example of a floodway channel to relieve a natural stream from flood waters.

5. Channel straightening

If the stream banks are properly aligned and strengthened to form a regular and confined channel, and if the bed is properly shaped and provision is made for floodways, then the need however that channel straightening as a measure for mosquito control will seldom arise. It may happen prevent the colonization of the snail hosts of schistosomiasis.

Before such an enterprise, which can be expensive and objectionable from the viewpoint of ecological balance, is attempted, careful attention should be paid to all the consequences.

An obvious one is the problem produced by the cut-off river bends. Rainfall and seepage water will be trapped in these unused river portions and the mosquito problem will be worse unless they are filled and graded, which is not a minor task. The engineer should, therefore, exercise judgement and decide where and when channel straightening is desirable.

IIID. DRAINAGE FOR AGRICULTURE AND LAND RECLAMATION

Contents

	<u>Page</u>
1. Introduction	70
2. Types of conveyance structures for drainage	71
2.1 Open ditches	71
2.2 Buried or underground drains	71
2.2.1 French drains	71
2.2.2 Buried conduits	72
2.2.3 Mole drains	72
3. Types of drainage	72
3.1 Surface drainage	72
3.1.1 General	72
3.1.2 Layout for surface drainage	72
3.1.3 Interceptor ditches	75
3.2 Subsurface drainage	75
3.2.1 General	75
3.2.2 Layout for subsurface drainage	76
3.2.3 Interceptor and relief drains	76
3.3 Combined surface and subsurface drainage	78
3.4 Drainage by pumping	79
3.5 Vertical drainage	79
4. Mosquito problems in drainage systems	80
5. Design of drainage systems	80
5.1 General remarks on design	80
5.2 Special considerations for mosquito control	81
6. Lining of ditches	81

1. Introduction

Drainage is the removal or elimination of unwanted water on the surface of the ground or in the upper layers of the soil. It may be unwanted because of harm to plant growth, damage to structures, or other objects. The accumulation of surplus water that has to be drained results from a combination of climatic, hydrological, topographical and soil characteristics as well as from irrigation and other land use practices.

In humid areas, drainage is mainly required for the removal of excess rainwater that either saturates the topsoil and collects in flat low-lying areas and land depressions, or

runs into streams and rivers to overflow and inundate the adjacent lands.

In arid and semi-arid areas, drainage is mainly required for the removal of the excess of irrigation water in canals, remaining on the surface of cultivated fields or seeping into the soil. Underground water (flowing from distant uplands) may rise to the surface and appear in swamps, marshes, etc. which need drainage. Drainage problems may also be caused by flood-water. Floods may have serious repercussions in loss of lives and property. Drainage systems may be destroyed by floods unless provision is made for the disposal of flood waters. In areas frequently exposed to flooding, the capacity of the drainage system must be sufficient to accommodate not only the surplus of irrigation water and the run off produced by normal rain storms but also the flood waters.

Mosquito production is generally associated with the absence of drainage systems or their inadequacy to cope with high intensity rainfall or with excess water resulting from over-irrigation, marsh expansion or inundations.

2. Types of conveyance structures for drainage

2.1 Open ditches

Although the purpose of the drainage ditch is the opposite of that of the irrigation canal, physically and hydraulically they are similar structures. In general, what has been said of open canals in subchapter IIIB is equally applicable to open drainage ditches. The main difference lies in the pattern of waterflow. In general, the waterflow in drainage ditches is less uniform and constant than in irrigation canals. Their usually neglected state of maintenance, with choking vegetation and pools of stagnant water, makes the waterflow even more erratic and more favourable for mosquito breeding. In such circumstances the problem of silting is more serious than that of scouring.

2.2 Buried or underground drains

2.2.1 French drains

French drains are trenches half filled with materials, such as rock, rubble, gravel and coarse sand, that present only minor resistance to water flow. This material is covered with a cloth fabric or, in its absence, a layer of palm leaves or long grass that prevents the movement of fine particles of silt and clay from the upper half to the porous section (see Fig. IIID-1).

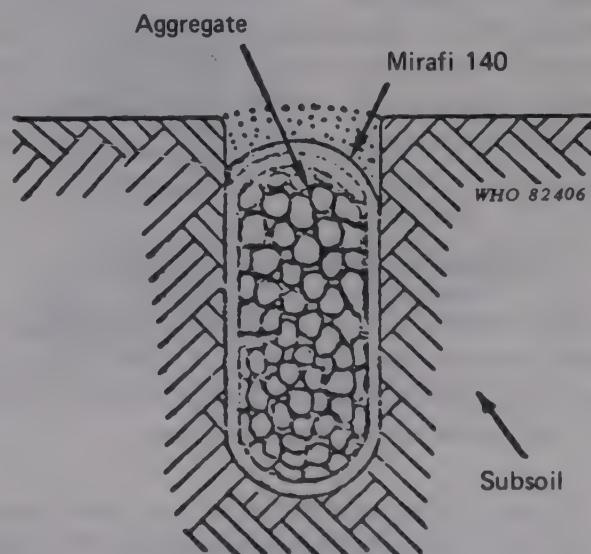
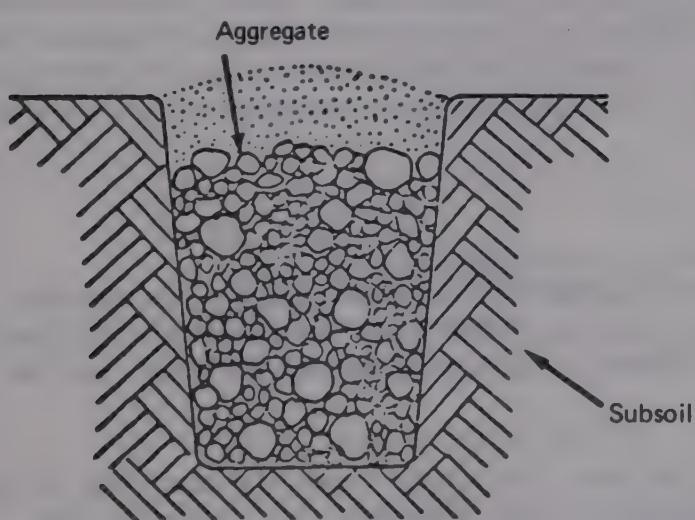


Fig. IIID-1. (a) A conventional French drain

Fig. IIID-1. (b) A French drain using filter cloth fabric.

2.2.2 Buried conduits

Buried conduits are an improvement on French drains. A pipeline with open joints or perforations is installed close to the bottom of the trench for the collection and conveyance of subsurface water. The pipeline is surrounded with coarse sand, gravel and rubble to hold it in place during construction. To prevent the passage of fine particles into the pipeline a cloth or leaf cover may also be required. The pipeline is made of baked clay or concrete pipes, or of bituminized fibre, metal or plastic tubes. The size ranges from 10 to 30 cm. Machines are available for opening the ground and installing perforated plastic tubing in lengths up to 150 m in one operation (see subchapter IIIH). Fig. IIID-2 shows four examples of buried conduits.

2.2.3 Mole drains

Mole drains are suitable for cohesive soils. They are formed by drawing a bullet-shaped former through the soil at the required depth. This former is made of steel and is welded to a sharp-edge vertical blade attached to the tractor that provides the power. As the tractor moves along, the blade makes a fine cut in the ground and the former creates the drain by displacing and compacting the soil material. Although the depth of the drain can be adjusted to correct surface irregularities, this method is mainly suitable for evenly sloping lands. Mole drains are not permanent and have to be re-formed periodically. For cohesive soils this type of drain may prove easy, cheap and effective.

3. Types of drainage

3.1 Surface drainage

3.1.1 General

Surface drainage usually involves the shaping of the land surface, the improvement of natural watercourses, and the construction of open ditches. It is applicable in particular to flat lands with relatively shallow topsoil over impermeable rock or clay subsoil which prevents the rapid percolation of rainfall, seepage water or overland flow to a deeper stratum. Surface drainage eliminates ponding, prevents prolonged saturation, and accelerates flow towards an outlet without eroding or silting the channel. Drainage ditches, when properly planned and maintained, should not cause mosquito breeding problems.

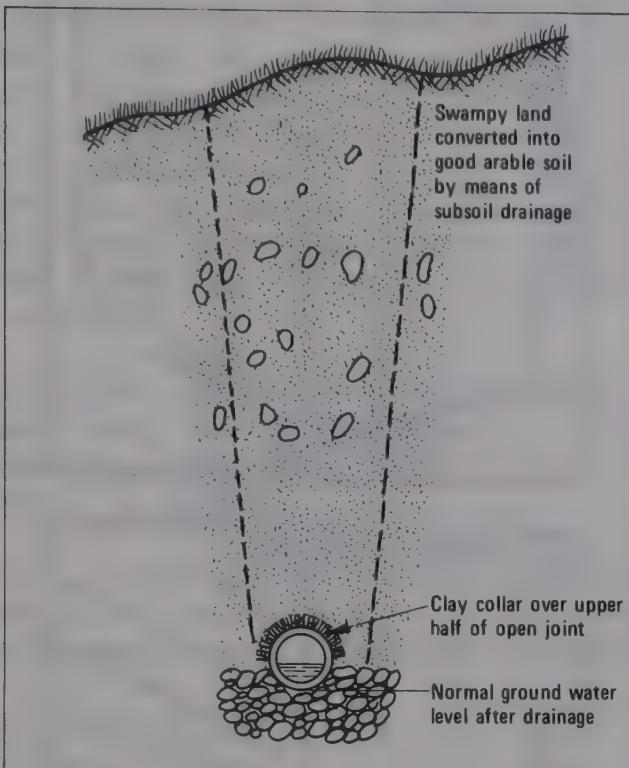
For the planning and design of surface drainage systems, the following investigations are usually required: (a) Topographic surveys; (b) soil surveys and location of critical erosion areas; (c) determination of existing and potential land uses; (d) precipitation and runoff investigation; (e) investigation of discharge outfalls, including frequency of high water levels in tidal marshes and lakes; (f) examination of profiles and cross-sections of existing streams and ditches; and (g) geological investigations and testing of channel stability, if required.

3.1.2 Layout for surface drainage

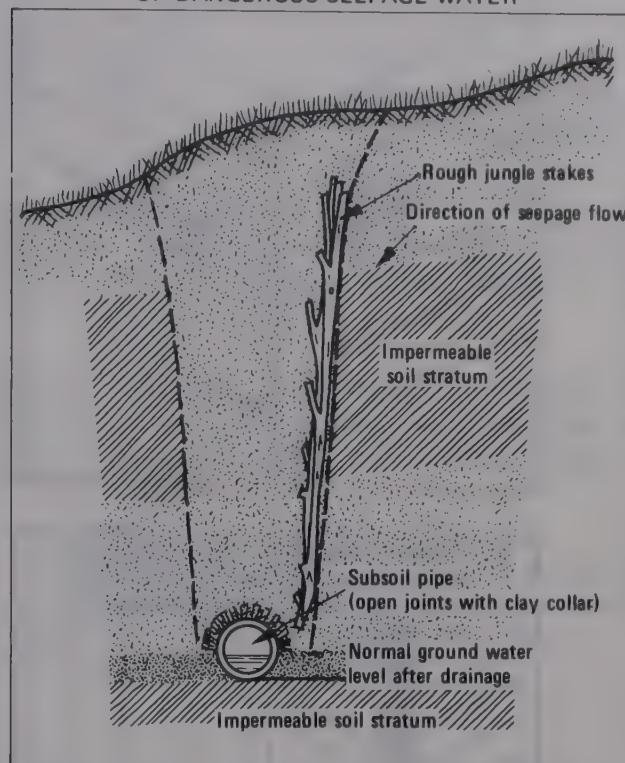
The location and design of drainage ditches are largely determined by the topography of the area and by any natural or artificial features, such as roads and canals that may restrict the general direction of the ditches, or streams, rivers, lakes and estuaries that may be useful as outlets to the system.

The most common layouts for drainage systems in flat irrigated land are the comb or grid-iron and the herringbone patterns of parallel sublaterals and laterals that receive the drainage water from cultivated fields. Laterals in a row are connected to a collector or disposal ditch that carries the water out of the irrigated area to an outlet of adequate capacity. Fig. IIID-3 shows typical patterns of drainage systems.

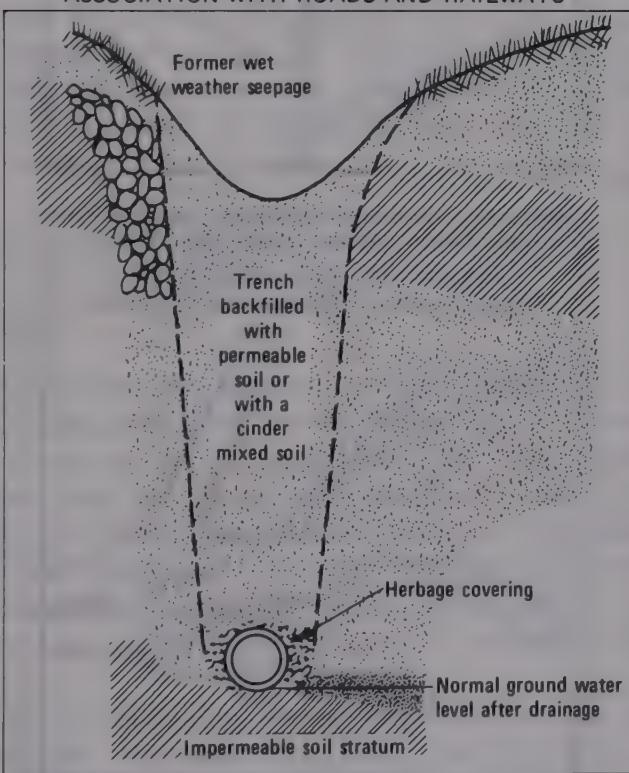
TYPICAL STYLE OF DEEP SUBSOIL DRAIN USEFUL IN MODERATELY PERMEABLE SOIL



SPECIAL PRECAUTIONS IN DEALING WITH A SUPERFICIAL LAYER OF IMPERMEABLE SOIL TO ENSURE THE DOWNWARD FLOW OF DANGEROUS SEEPAGE WATER



A SURFACE AND AN UNDERGROUND DRAIN MAY SOMETIMES BE USEFULLY ACCOMMODATED ALONG THE SAME DRAINAGE LINE, PARTICULARLY IN ASSOCIATION WITH ROADS AND RAILWAYS



WHERE STONES ARE PLENTIFUL IN LAND REQUIRING DRAINAGE, A CHEAP AND EFFICIENT SUBSOIL SYSTEM CAN BE MADE OF STONES

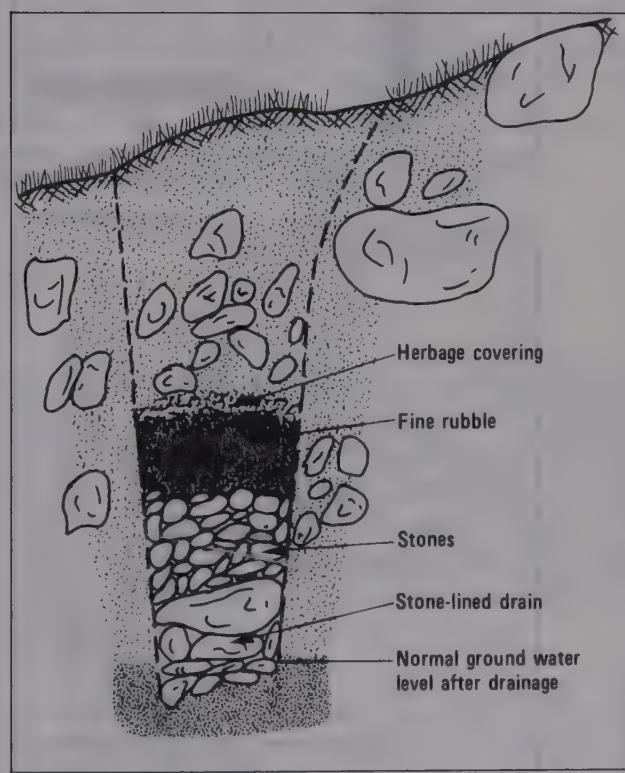


Fig. IIID-2. Examples of buried conduits.

(Adapted from: Kolta, S. Environmental management as a malaria control method. Manila, WHO Regional Office for the Western Pacific, 1979 (Document prepared for the Regional Workshop for Directors of the Antimalaria Programme, Kuala Lumpur, September 1979)).

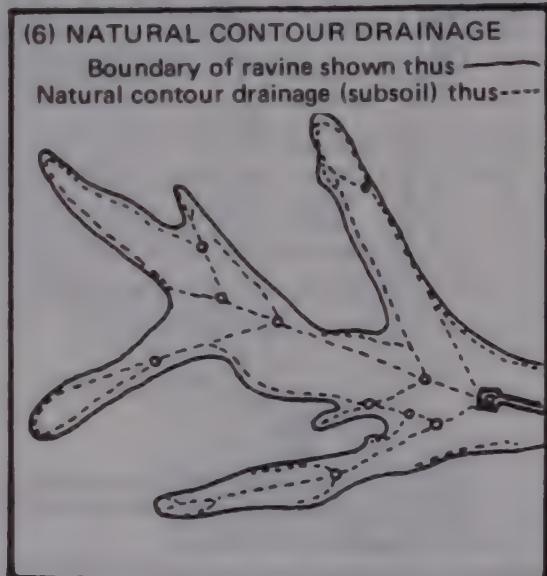
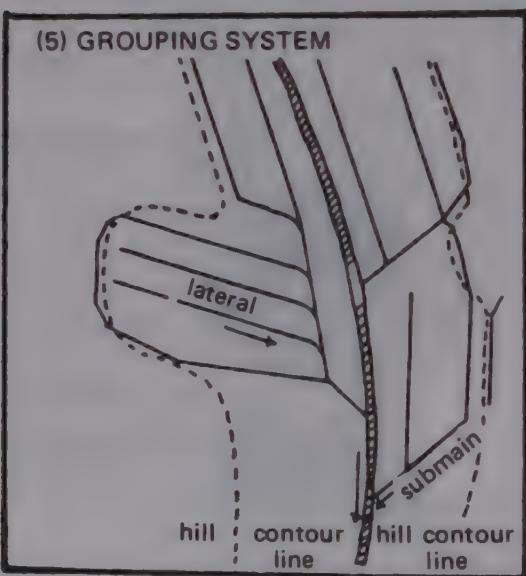
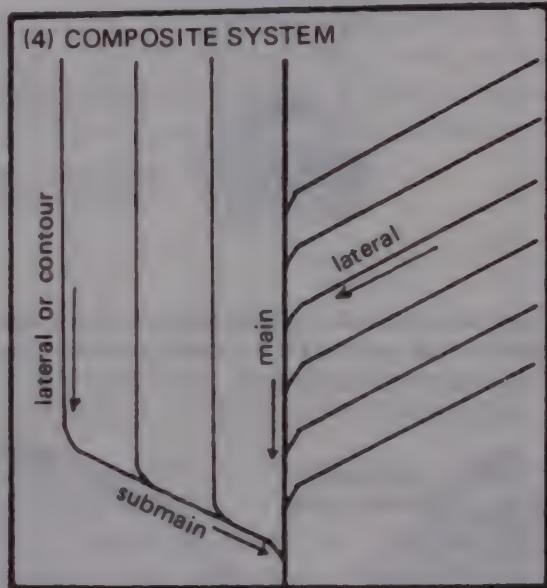
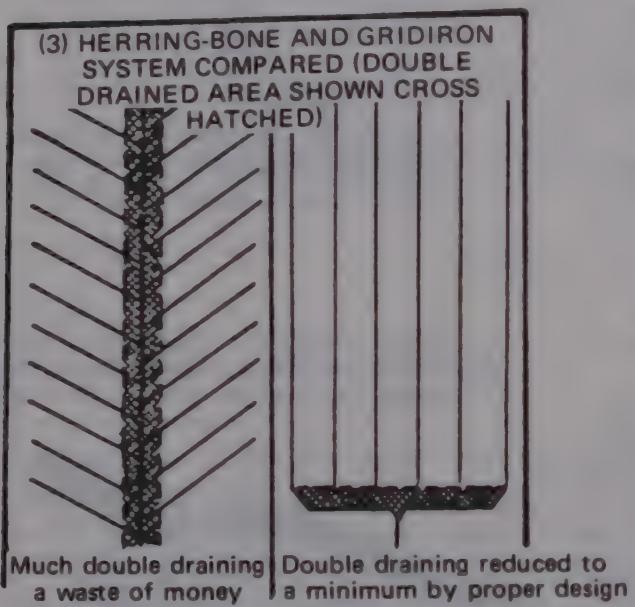
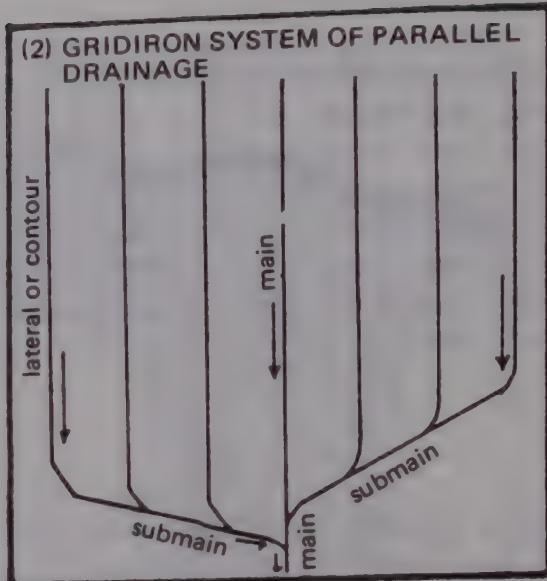
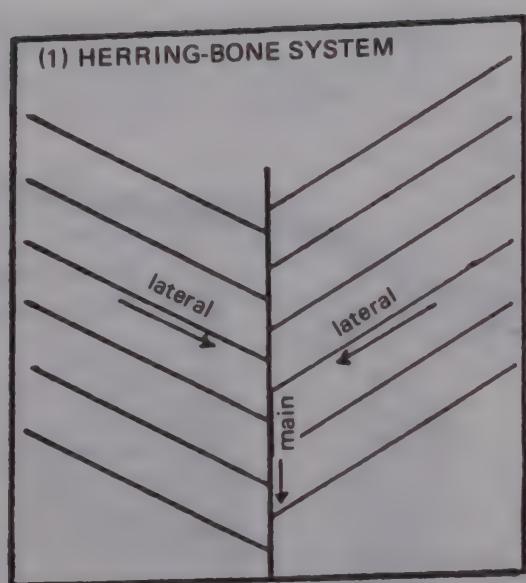


Fig. IIID-3. Typical drainage systems.

(Source: Kolta, S., op. cit.)

Collector ditches should be designed to convey drainage water efficiently and rapidly; this calls for steep gradients and maximum water velocities consistent with the erosive characteristics of the soil. The location of collector ditches is subject to fewer restrictions than that of irrigation canals where the maximum command of land is imperative. As far as topography allows, ditches can run straight to the outlet, thus reducing length, increasing the gradient, and permitting smaller channel cross-sections. A small amount of scouring during the short periods when the ditch works at full capacity is not as objectionable as it would be in irrigation canals; much of the scour is compensated by silting when the ditch works at lower flows. However, in steep ground with unstable soil, collector ditches should be designed to avoid producing erosive water velocities. Straight channels are possible if, at convenient intervals, a drop or chute is provided to dissipate the energy of flow without producing erosion.

The outlet of a collector ditch discharges into a receiving watercourse (stream, river, etc.) or water body (lake, estuary, etc.). The receiver should be adequate under the most adverse conditions, when the collector ditch is at full discharge and the flow or water level in the receiver is maximum.

Where the receiving watercourse or water body is distant and the land is very flat, it may be necessary to resort to pumping to evacuate the drain. If the subsoil conditions are favourable, however, vertical drainage may offer a solution (see section 3.5 below).

3.1.3 Interceptor ditches

Interceptor ditches are needed to protect the land against overland flow produced by intense rainfall and floods. Interceptors usually run along the contour, with the minimum practicable gradient, or along the foot of hills where the land slope becomes flatter. They should be sufficiently deep to intercept seepage water as well. At the time of construction the excavated material is often placed on the lower side of the ditch to form a levee that increases the capacity of the ditch. Like other ditches, interceptors should be inspected regularly and any vegetation, sediment and other obstructions should be removed, as required. Levees should be kept in good repair. Water diverted by the interceptors is carried away by collector or disposal ditches.

3.2 Subsurface drainage

3.2.1 General

The objective of subsurface drainage is to lower the water table to a level which favours crop production, ensures road stability and construction safety, or serves other purposes. This objective can be accomplished by deep open ditches or by subsurface drains.^a In fact open ditches that collect surface water can also be used for subsurface drainage if they are deep enough to lower the water table to the desired level and have sufficient capacity to serve the dual purpose. As the volume of earthwork is in direct proportion to the square of the ditch depth, the use of open ditches for subsurface drainage is usually limited to situations where the water table does not have to be lowered beyond depths of 1.5 m.

Another consideration, also linked with the depth of open ditches, is that the area occupied by the ditches is lost to cultivation. The flat side-slopes that are required to ensure stability in erosive soils increase the loss of useful land.

^a In this subchapter, the term drain is applied only to a covered conduit that usually runs underground; an open conduit is referred to as a ditch.

When, for the required lowering of the water table, the bed of the ditch must be at depths beyond 1.5 to 2.0 m, it may be more practical and economical to use a closed conduit instead of an open ditch. The closed conduit requires a minimum of excavation for its installation. Unless the soil is very unstable, trenches can be dug with vertical sides; they remain open only for the time needed to lay the conduit, which can be kept to a minimum. Trenching machines (as described in subchapter IIIH) can open the ground and lay the pipe as the machine moves along.

The widest application of subsurface drainage is in irrigated land. Besides preventing waterlogging, it allows aeration and the leaching of salts in the plant root zone. The amount of water to be removed depends on the irrigation method applied, the quantity and quality of irrigation water, and the nature of the topsoil.

Data on soil permeability, plant consumptive use of water, water table levels, salinity and surface topography are as necessary for the design of drains as for that of irrigation canals. In fact, information on soil permeability and groundwater conditions is more important for drainage purposes.

3.2.2 Layout for subsurface drainage

The patterns of laterals and collector ditches described for surface drainage are also appropriate for subsurface drainage, whether this is performed by ditches or drains. The layout of buried drains is less restricted by topographic gradients and irregularities than is that of open ditches. Drains do not take away any area from cultivation and allow free movement over the land. These advantages may be decisive in the selection of a system of buried drains, even when open ditches could serve the same purpose.

3.2.3 Interceptor and relief drains

Interceptor drains or ditches are aligned perpendicularly to the flow of groundwater, regardless of minor topographic irregularities, and have a very slight slope. Relief drains or ditches run approximately parallel to the flow of groundwater and are laid with a slope more or less parallel with the hydraulic gradient of the water table.

Relief drains or ditches produce a more uniform lowering of the water table on both sides of the conduit. Interceptor drains or ditches lower the water table more effectively on the lower or downslope side of the conduit. For this reason, interceptor drains or ditches are usually located near the upper edge of the wet area to be protected. This is illustrated in the four sketches (Fig. IIID-4, (a)-(d)), which show the before-and-after water-table levels for the ditches and drains of the two types, relief and interceptor. Fig. IIID-5 is an isometric sketch showing both relief and interceptor drains in place; it illustrates the alteration of the original water table produced by drainage. It may be noted that the original hydraulic gradient slopes in the same direction as the relief drains but is flat in the direction of the interceptor drains. This shows that the slope of the original water table influences the functioning of interceptor drains but not the functioning of relief drains.

The choice between interceptor and relief drains largely depends on the depth of the soil above the impervious layer or barrier (barrier depth), and on the hydraulic gradient of the water table at the site. Preference should be given to interceptor drains where, other factors being suitable, the barrier depth is not more than twice the drain depth, since a shallow barrier depth reduces the effect of relief drains. Preference should be given to relief drains where, other factors being suitable, the hydraulic gradient of the water is very slight, as this reduces the effect of interceptor drains.

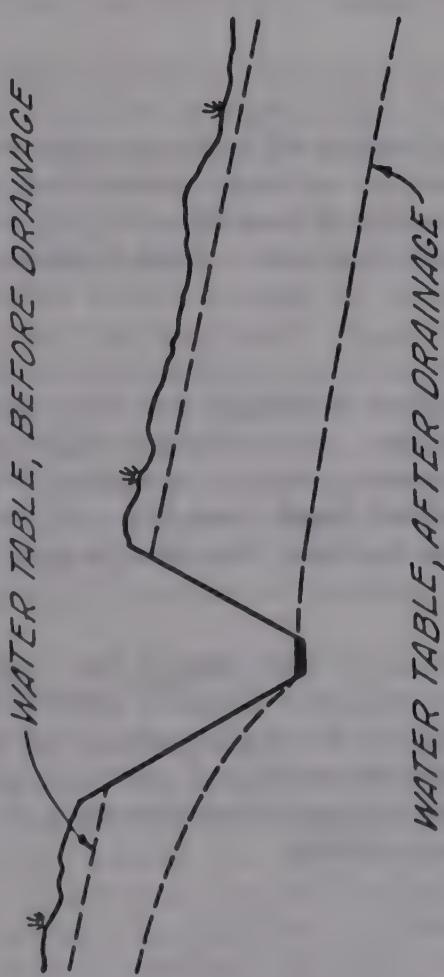


Fig. IIID-4. (a) Interceptor ditch.

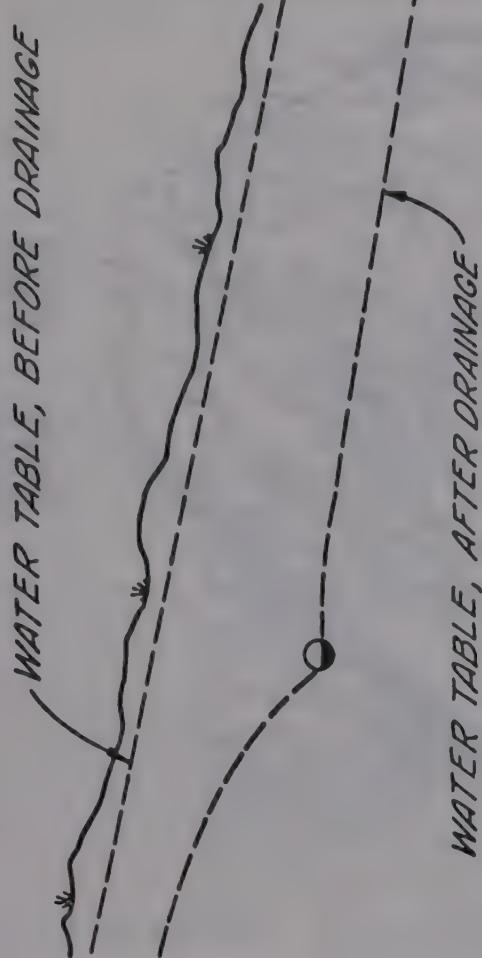


Fig. IIID-4. (b) Interceptor drain.

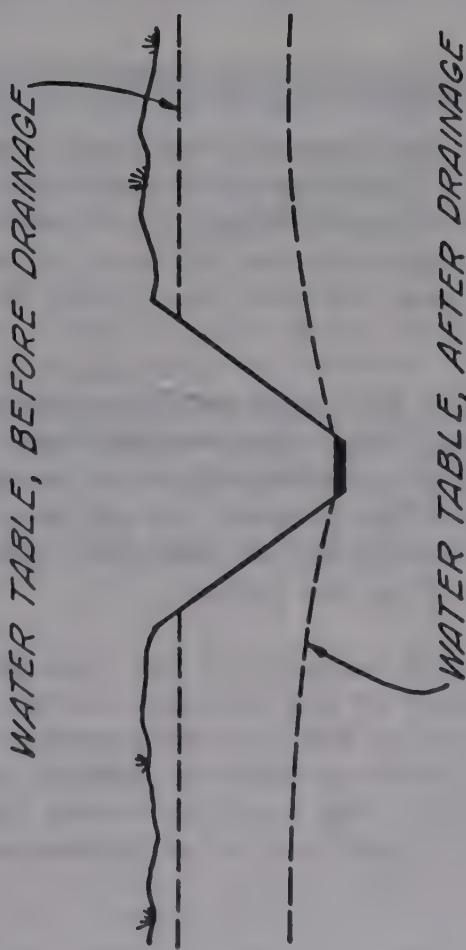
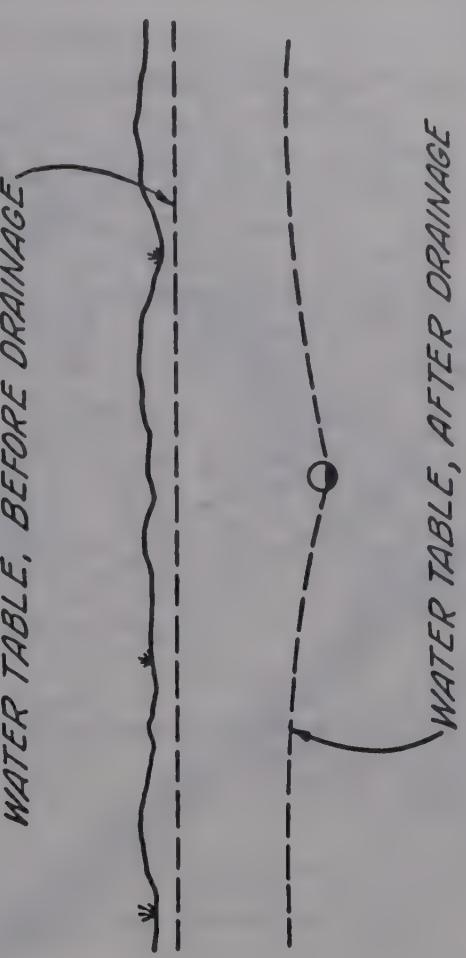


Fig. IIID-4. (c) Relief ditch.

Fig. IIID-4. (d) Relief drain.



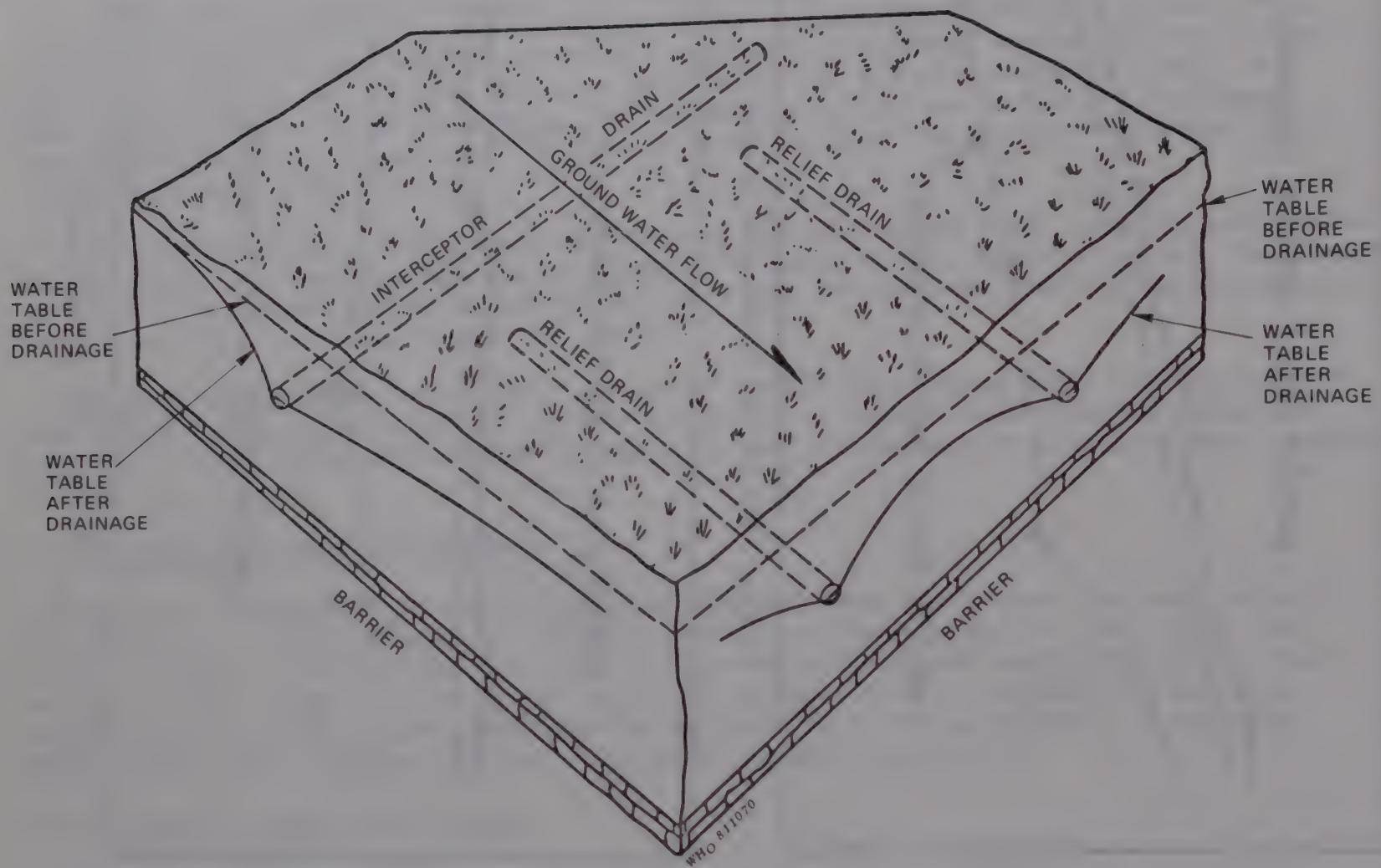


Fig. IIID-5. Isometric profiles of relief and interceptor drains.

3.3 Combined surface and subsurface drainage

It is a common practice to install a single system to dispose of both surface and subsurface waters. In a system of open ditches, those which are to collect subsurface water are dug to the required depth, and those which receive the surface runoff only are shallow. The deep subsurface ditches act also as collector or disposal ditches; they receive the surface water from the shallow ditches through drop structures of various types which prevent scouring.

In a system of buried or underground drains for subsurface drainage and open ditches for surface drainage, each sector works more or less independently. It is at the collector ditch that the surface and subsurface sectors meet, through appropriate drop structures and protected outlets, for the disposal of all the water from the drained land (see Fig. IIID-6). Surface water should not be admitted into underground drains because the debris and sediment it carries can plug the drain.

The required capacity of the dual-purpose collector ditch is the sum of the individual design discharges of the surface ditches and the subsurface drains. Surface water includes irrigation water at the tail of canals, runoff from rainfall, and occasional flooding. Subsurface water includes lateral seepage, capillary water and some vertical percolation. Under normal conditions, the capacity of the open collector ditch is more than adequate to receive both. However, the capacity of collectors should always be checked.

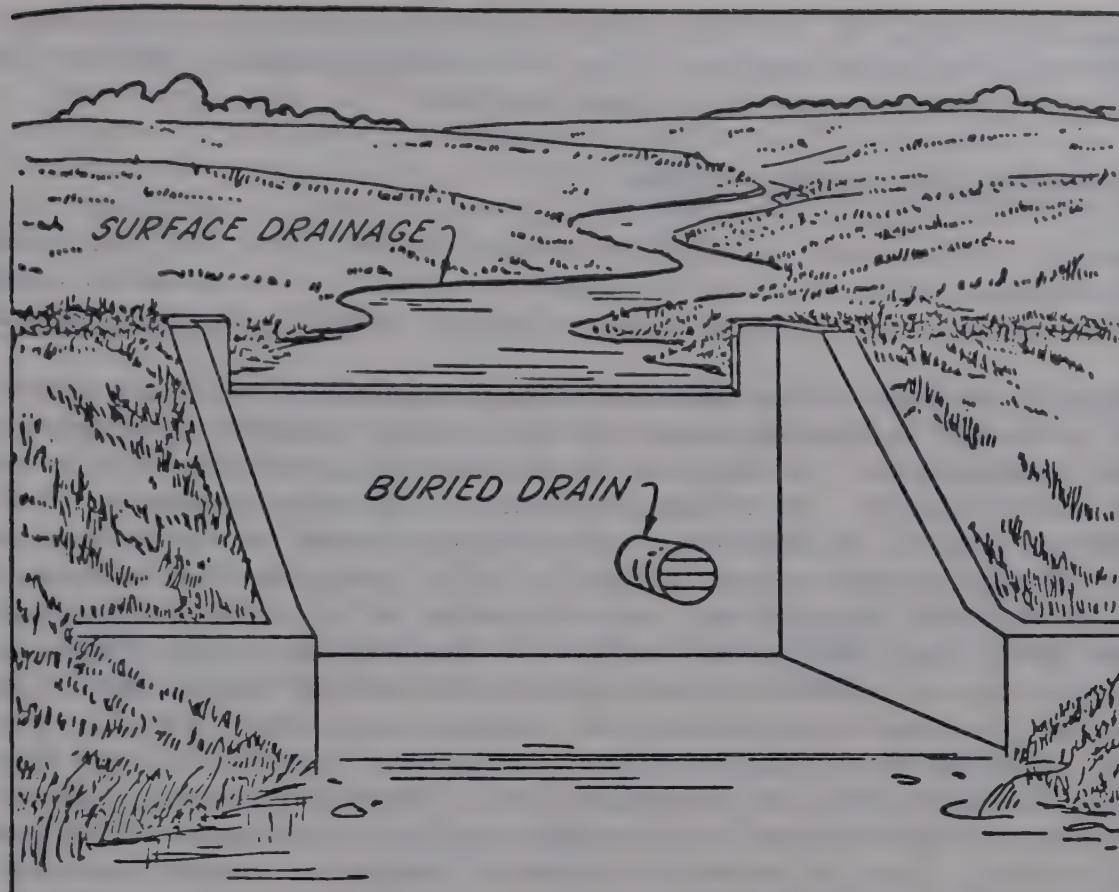


Fig. IIID-6. Drop structure for surface drainage and protected outlet for a buried drain.

3.4 Drainage by pumping

There are two different situations where the pumping of surplus water may be required.

(a) When the land slope and hydraulic gradient of the water table make it possible to operate a conventional system for the drainage by gravity of surface and subsurface waters, but at the lower end of the drained area there is insufficient head to ensure discharge. In such a situation the practical solution is to pump the drainage water either into a collector ditch on a higher elevation if the topography is suitable, or else through a pipeline conveying the water under pressure to the point of disposal.

(b) When the hydraulic conductivity of the soil is high, it may be possible to replace the network of subsurface drains with a system of wells from which the water is pumped to collector ditches. A series of well points, driven to the required depth and connected to a common pump, may prove to be a practical way of lowering the water table. However, before attempting drainage by pumping, which involves high initial and operational costs, it is necessary to investigate subsoil characteristics and to carry out tests to determine the effect of pumping and its area of influence on the water table. Such information is essential before deciding on well depths and spacing.

3.5 Vertical drainage

Where the land is so flat that there is practically no slope to allow surplus water to flow, as happens in swamps, bogs or marshes, vertical drainage may offer a solution. In cases where the topsoil is waterlogged because percolation is prevented by an impervious layer, while at lower depths the subsoil material is porous and capable of storing water, it is possible to discharge the surface and subsurface water into the pervious deeper strata by breaking through the barrier of impervious material. This can be achieved by vertical shafts driven or drilled through the soil and protected against caving either by a casing (similar to that used in wells) or by filling the shafts with stones, gravel and coarse sand (see sub-chapter IIIE, Fig. IIIE-2).

Wherever perched water is a problem, the possibility of vertical drainage should be explored. However, in view of the risk of polluting the groundwater in the lower strata, vertical drainage should be used with extreme caution.

4. Mosquito problems in drainage systems

As the purpose of drainage is to remove unwanted water from land surfaces, thus eliminating mosquito breeding sites, it is in principle compatible with mosquito control. However, mosquito problems do exist in drainage systems and are usually due to inadequate maintenance.

Some irrigation schemes do not have a drainage component, and experience has shown that the stagnation of excess irrigation water creates serious mosquito problems with consequent rises in malaria transmission, in addition to agricultural problems such as waterlogging and an increase in soil salinity. In schemes that have a drainage component, the funds available for maintenance are usually insufficient and are mostly spent on irrigation canals. This is because irrigation canals must be kept in good repair, otherwise the delivery of water to the cultivated fields will be impaired and crop production will suffer. The condition of the drainage system has no such perceptible effect on crop yields. It is therefore no surprise to see so many drainage ditches in a most deplorable state of repair with eroded banks and beds, deteriorated alignments and slopes, and abundant vegetation growth. Sometimes even garbage becomes piled up in drainage ditches. Under such conditions, the flow in the ditches is sluggish when the rain comes and isolated pockets remain afterwards. Both situations are favourable for mosquito production. The various auxiliary structures in a drainage system, such as junction boxes, sand traps or grit chambers, may also become important mosquito sources unless they are properly cared for.

5. Design of drainage systems

5.1 General remarks on design

The design of drainage systems may involve more elaborate techniques than the design of irrigation systems, because the problem is more complex.

First, the quantity of water to be conveyed for irrigation can be determined with sufficient accuracy from the consumptive use of plants to be cultivated and from the permeability and other characteristics of the topsoil. The amount of water to be drained depends on factors which are not so easily estimated. Regarding water sources, for instance, precipitation, surface runoff, flooding, inflow from uplands, localized seepage, and the drainage quantities for leaching must all be taken into account.

Secondly, the hydrology of the subsoil plays a minor part in the design of irrigation canals; the presence of a high water table is important only if it allows the amount of water supplied to be reduced. In the design of drainage ditches, it is essential to have detailed information on the water table, periodic variation in levels and hydraulic gradients, its effect on plant growth, salinity, etc.

Thirdly, the investigation of soil characteristics must be carried out to lower depths, usually 2 to 3 times as deep as the proposed ditch or drain, and be more comprehensive. The general composition and permeability, granulometry, void or pore space, organic matter content, etc. for each layer of different material will have to be determined. The detailed discussion of this subject is beyond the scope of this manual. For further information, the reader is referred to technical publications such as that prepared jointly by FAO-UNESCO.^a

^a Food and Agriculture Organization & United Nations Educational, Scientific and Cultural Organization. Irrigation, drainage and salinity: An international source book. London, Hutchinson, 1973.

The engineer will first decide the type of drainage that is most suited to the given situation, the type of conveyance structure to be used, the location of the outfall, and the general pattern of the scheme. He will then proceed with the detailed design of the ditches, conduits, pumping stations if required, and other necessary ancillary structures. The overall economy is as important in drainage as in irrigation, and the engineer should carefully consider the various technical alternative plans and their cost comparison before a definitive plan is recommended.

5.2 Special considerations for mosquito control

As can be seen from section 4 above, mosquito breeding occurs in drainage systems primarily because of poor maintenance of open ditches and ancillary structures. Therefore, in principle, the radical solution to the problem is to avoid the use of open ditches and, if this is not possible, to maintain the ditches in good condition. Specifically, the following environmental management measures should be given due consideration for incorporation in the design and operation of any drainage system: (a) use of buried drains instead of open ditches as far as possible; (b) lining of the ditches or lining of the invert, if open ditches have to be used; (c) good alignment of ditches and avoidance of sharp curves; (d) ditch flushing; and (e) effective maintenance of the scheme.

The discussions in subchapter IIIB on curves in canals, gates and siphons, and effective canal maintenance in irrigation schemes are also applicable to drainage systems, and it is suggested that the reader should refer back to that subchapter for details. Some additional remarks on the lining of ditches are given in section 6 below.

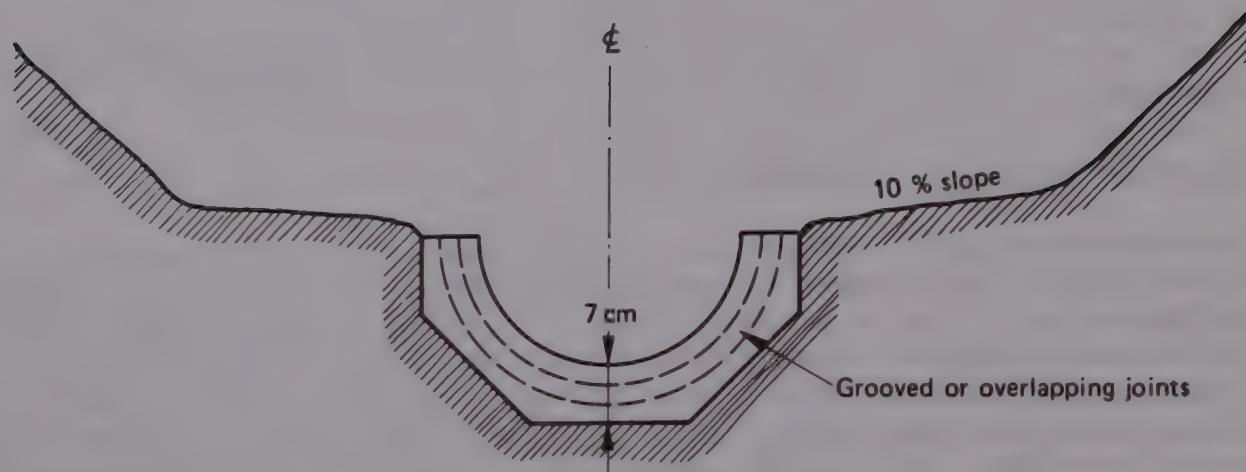
6. Lining of ditches

Although the lining of ditches is even less generally practised than the lining of irrigation canals, the advantages derived from lining are as great for ditches as for canals. In fact, lining as a means for preventing weed growth is more necessary when the flow is slow, intermittent and erratic, as it is in ditches, than when it is rapid, constant and uniform, as it is in irrigation canals (see subchapter IIIB, section 6).

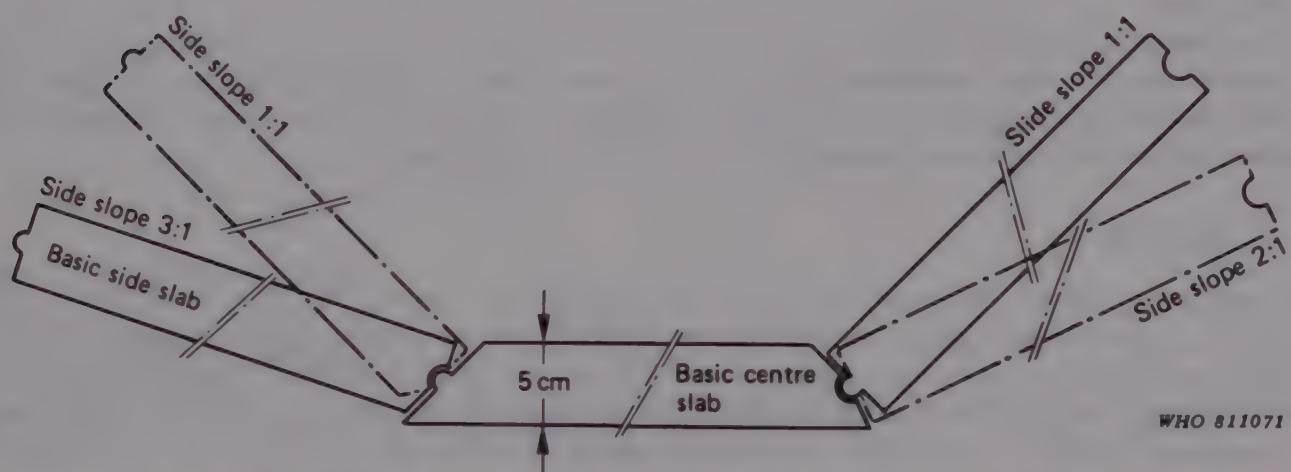
To prevent obstructing the seepage into subsurface drainage ditches, porous linings can be produced using a dry or non-mortared revetment of brick, stone, concrete or stone blocks, or a continuous concrete lining provided with weep holes.

A common practice for ditch lining is to use precast sections of Portland cement concrete, shaped and assembled to form a narrow invert along the centre line of the ditch, which permits free flow at low water levels. The bed is filled and graded to lead the water flow towards the centre (see Fig. IIID-7). The main advantages of this lining are that it does not interfere with lateral seepage at all and is much cheaper than the full-perimeter type of lining. This invert lining can be combined with grass-covered sides that stabilize the banks and make steeper side slopes possible. Such "vegetated" waterways are produced by seeding the channel with grass of the short-leaf and matted-root type. The grass cover should be kept short and dense by regular cutting. Resistance to erosion is such that the channels can withstand water velocities of 1.25 to 2.00 m/s. In the design of vegetated waterways, the roughness coefficient in Manning's formula^a is taken as $n = 0.04$, which corresponds to freshly cut grass. The cross-section of the waterway can be parabolic, triangular or trapezoidal. When the crossing by farm machinery is foreseen, the side slopes should not be steeper than 1:4.

^a The use of Manning's formula is explained in Chapter VII, section 4.2.



a) Typical section of a drainage ditch with a precast concrete invert along the centre-line



b) "Universal" slab construction for many sizes and shapes. With a basic centre slab and a basic side slab, different side slopes (1:1, 2:1 & 3:1) can be obtained by rotating bearing joint (about 2 cm cylindrical). Usual size 5 cm thick X 80 – 100 cm long X 20 cm wide. However, it may not be easy to cast.

Fig. IIID-7. Precast concrete invert sections.

IIIE. DRAINAGE FOR MOSQUITO CONTROL

Contents

	<u>Page</u>
1. Introduction	83
2. Criteria applied to drainage for mosquito control	84
3. Small drainage works	84
3.1 Small water pools, holes, etc.	84
3.2 Water collections at waterpoints	85
3.3 Soakaways	87
3.3.1 Seepage pits	87
3.3.2 Soakage trenches or drainfields	87
3.3.3 Evapotranspiration bed or soakaway mound	89
4. Large-scale drainage works	91
4.1 Coastal situations	91
4.1.1 Diking and dewatering of coastal swamps	91
4.1.2 Open marsh ditching	92
4.1.3 Clearing and maintaining open stream outlets	92
4.2 Inland situations	93
4.2.1 Swamps located in the vicinity of waterbodies	93
4.2.2 River swamps	94
4.2.3 Swamps resulting from seepage or springs	94
4.3 Investigations and studies required for drainage works	96
5. Methods for ditch excavation	97
5.1 Hand-excavated ditches	97
5.2 Machine-excavated ditches	98
5.3 Ditching with explosives	98
5.4 Precautions during blasting	101

1. Introduction

In principle, drainage techniques for mosquito control do not differ from those for any other purpose. As has been stressed in subchapter IIID, proper drainage (regardless of its objective) helps reduce mosquito populations by eliminating or reducing habitats suitable for the development of mosquito larvae.

It is, however, convenient to treat the subject separately because the criteria differ with the objective, and because there are specific situations where either small or large drainage operations that are needed for mosquito control purposes alone are generally neglected owing to lack of interest or economic incentive.

2. Criteria applied to drainage for mosquito control

(a) Distance. The drainage of mosquito habitats can be limited to well-defined and relatively small shallow areas surrounding villages, towns and other human settlements. Mosquitos have a range of flight, the maximum figures of which have been determined for different species through entomological studies (see Annex 1). For practical purposes, however, anopheline mosquito control operations within a radius of 1.5-2 km from human habitation provide reasonable protection. It is usually not necessary to extend drainage works further afield if, within this radius, the elimination of mosquito habitats is thoroughly pursued.

(b) Timing. Except for the tropics where the climate is warm and humid all the year round and malaria transmission is usually perennial, the need for drainage of mosquito habitats is limited to well-defined periods of the year. In most malarious regions in the temperate zone, there are seasons of intensive mosquito production and increased disease transmission. It is during these periods that drainage is particularly important.

(c) Depth. The drainage of mosquito habitats can be limited to the removal of surface water without the need to lower the water table more than a few centimetres below the low points of the ground surface. In contrast, the water table needs to be lowered to below the plant root zone for agricultural drainage.

(d) Duration. The drainage of mosquito habitats may take as long as the time required by the mosquito to develop from the egg to the adult (4 days to 3 weeks, according to the species and local climate). Therefore, drainage for mosquito control can take longer and a smaller ditch section can be used than is the case of drainage for crop cultivation. Young plants can seldom withstand submergence for more than two or three days, while for mosquito control water may remain longer on the surface provided that one or two days of total dryness follow.

(e) Mosquito species. The drainage of mosquito habitats should be limited to the existing and potential breeding places of the vector concerned. The concept of "species sanitation" requires drainage to be directed against the particular mosquito species that is a confirmed vector of disease. In the absence of disease vectors, drainage will not be a public health measure but may be needed for agricultural, pest mosquito control or other purposes.

From these remarks it may be inferred that drainage for mosquito control has less stringent requirements than agricultural drainage. However, it should be noted that complete drainage of low-lying areas may be required for effective mosquito control even though it may not be necessary for agricultural purposes.

3. Small drainage works

There are many instances in and around human settlements where small water collections which will not seep away or evaporate in a few days are completely disregarded. It is the responsibility of the health administration to call the attention of local authorities and the public in general to the health risk represented by these small but significant mosquito habitats. In addition to advising and persuading others to carry out the needed tasks, the health administration should be capable of taking positive action to correct the situation.

3.1 Small water pools, holes, etc.

One of the more common and simple source reduction ditching operations is the drainage of temporary rain or runoff pools which develop in depressions on sloping ground or which occur below seepages or springs in the vicinity of human habitation. Frequently these small pools are drained by short ditches that carry the water downgrade to where it can spread out over a gently sloped area of pervious soil so that the water disappears underground. Alternatively the ditch may lead to a stream or other outfall which carries the water away. If only a short ditch is needed, its size, location and shape may be dictated more by convenience of construction than by rigid engineering design. The input of labour is minimal and if the ditch should

fail because of inadequate design, it can be improved at little cost when the time for maintenance comes round. Furthermore, if the capacity of the ditch is temporarily exceeded while runoff is at a maximum, no great damage is done.

Water pools are also found in open spaces, streets, yards and other places inside villages, towns and cities, because of lack or inadequacy of sewerage, both for storm and waste waters. These pools may be drained if they are located on sloping ground or if a suitable drainage ditch is available nearby to carry away the water. In most instances, however, this is not possible and consideration should be given to other methods of control such as filling and grading (see subchapter IIIF) or larvicing. The permanent solution to the problem of water accumulation in urban areas is the construction of sewerage.

3.2 Water collections at waterpoints

One problem frequent in developing countries is the lack or inadequacy of drainage of the surplus water from public fountains, taps, handpumps, etc., as well as water from pipe leaks, seepage to the ground surface, and various misuses of community water supplies. It is possible that this problem will increase significantly with the expansion of such supplies during the present International Drinking Water Supply and Sanitation Decade (1981-1990), promoted by the United Nations system. There is no doubt that many water supplies will be provided, but how much attention will be given to the drainage of waste water resulting from the increased use of water is not clearly specified.

The typical pool and muddy areas around water supply points, cattle watering troughs, public laundries, etc. should be eliminated. Concrete aprons round the service point will prevent ground puddling and a drain pipe should remove the waste water effectively (see Fig. IIIE-1). Where a drain or a drainage ditch is not available to receive and carry away the waste water, a suitable soakage arrangement such as a seepage pit, a drainfield or an evapotranspiration bed may be used. In the use of evapotranspiration beds, proper maintenance is needed to avoid accumulation of seepage water at the toe where a mosquito breeding site may develop. Details of these methods are given in section 3.3 below. Where the geological formation is suitable, i.e., where a pervious layer exists underneath the top impervious layer, it may be possible to use a vertical drain to get rid of the waste water (see Fig. IIIE-2). However, this method may result in pollution of ground water. Vertical drainage is discussed in subchapter IIID, section 3.5. When the service point is supplied by a shallow well, the soakaway pit or the drainfield should be located at a safe distance to prevent contamination of the source. This distance depends on the soil characteristics, but it should be 30 m or more.

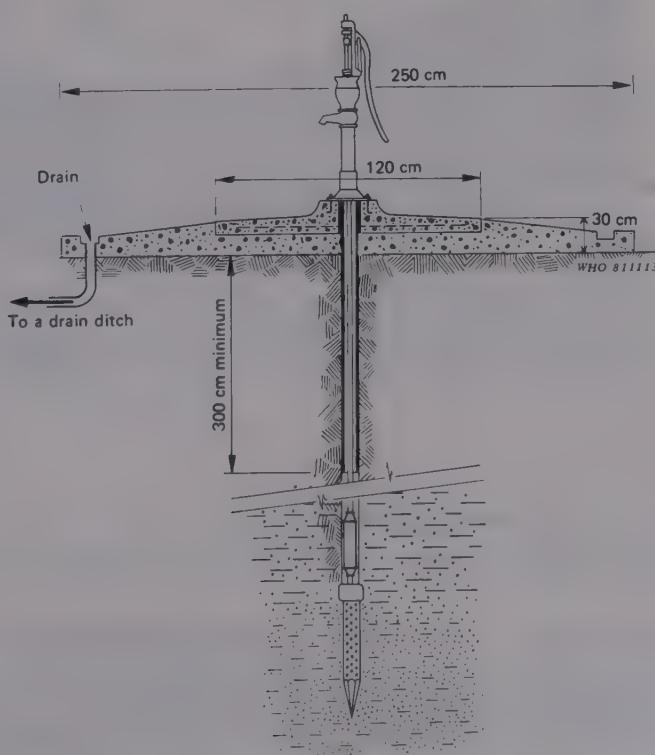


Fig. IIIE-1. Tube well and hand pump with concrete apron and drain.

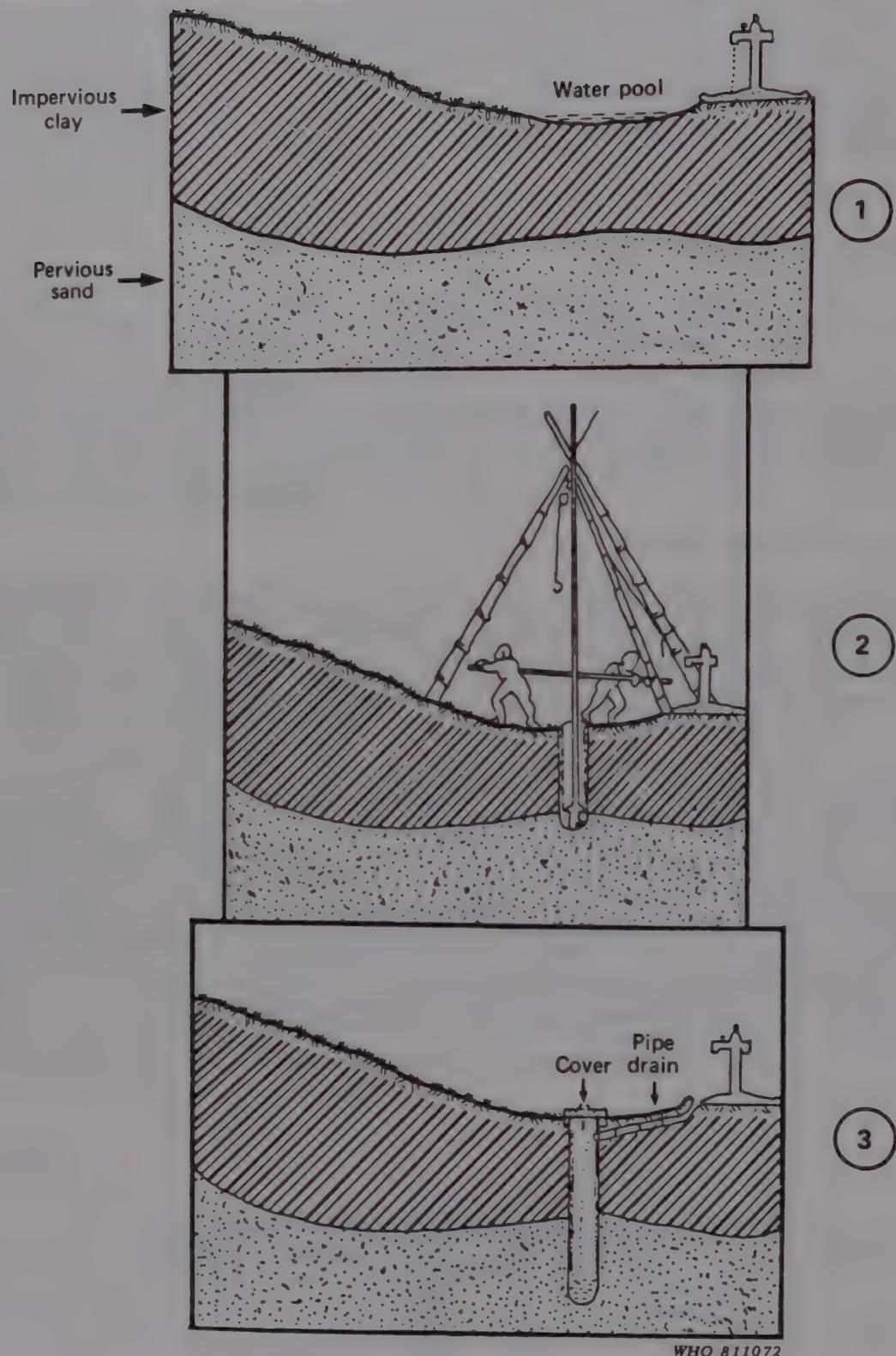


Fig. IIIE-2. An example of vertical drainage.

The waste water from a water tap is removed by a vertical drain.

(Adapted from: Kolta, S. Environmental management as a malaria control method. Manila, WHO Regional Office for the Western Pacific, 1979 (Document prepared for the Regional Workshop for Directors of the Antimalaria Programme, Kuala Lumpur, September 1979)).

The WHO Expert Committee on National Environmental Health Programmes: Their Planning, Organization and Administration^a recognized the fact that the improvement of water supplies creates a need for proper disposal of used and waste water. Mosquito breeding is a direct consequence of disregarding this fact.

3.3 Soakaways^b

A soakaway is a hole or a set of trenches in the ground filled with stones through which waste water can seep away into the surrounding soil.

Soakaways are usually used for the disposal of waste water from septic tanks, aqua privies and other similar small sanitation installations. They can also be used as a method for ultimate removal of the drainage water from waterpoints.

3.3.1 Seepage pits

One form of soakaway is a seepage pit which is dug into porous material in places where the water table is not high. It is commonly 2-5 m deep and 1-2.5 m in diameter. It is lined or filled with stones at least 50 mm in size, as shown in Fig. IIIE-3. Seepage pits are not appropriate where the soil is too fine for water to seep into it.

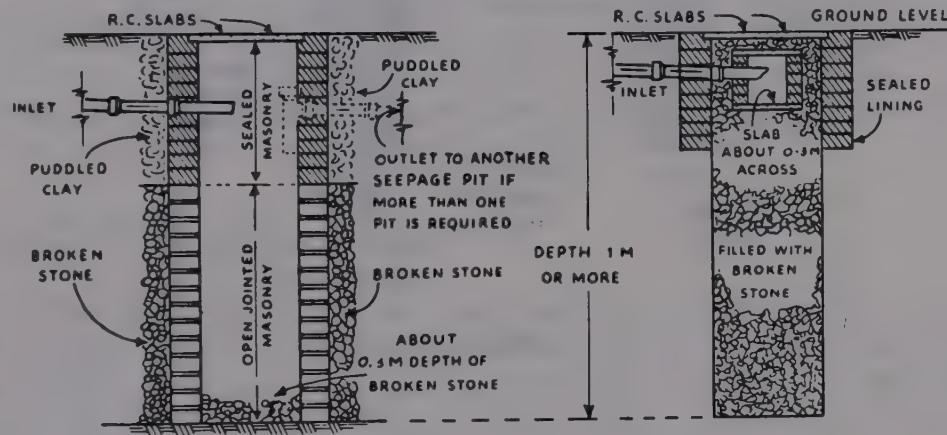


Fig. IIIE-3. Two kinds of seepage pit. (Adapted from: Ross Bulletin No. 8, p.40)

3.3.2 Soakage trenches or drainfields

Soakage trenches are filled-in ditches containing open-jointed pipes, usually of 100 mm diameter, laid on gravel or broken stone. They allow the waste water to be widely distributed through a large area of soil. Normally several trenches are dug, each 15-30 m long, and connected together to make a drainfield.

^a WHO Technical Report Series, No. 439, 1970.

^b This section is based on: Feachem, R. & Cairncross, S. Small excreta disposal systems. London, the Ross Institute of Tropical Hygiene, 1978 (Ross Bulletin No. 8).

A typical arrangement is shown in Fig. IIIE-4. The trench width usually ranges from 0.3 to 0.5 m and the gravel depth below the pipe from 0.6 to 1 m. The recommended minimum trench spacing is 2 m or twice the trench depth, whichever is greater.

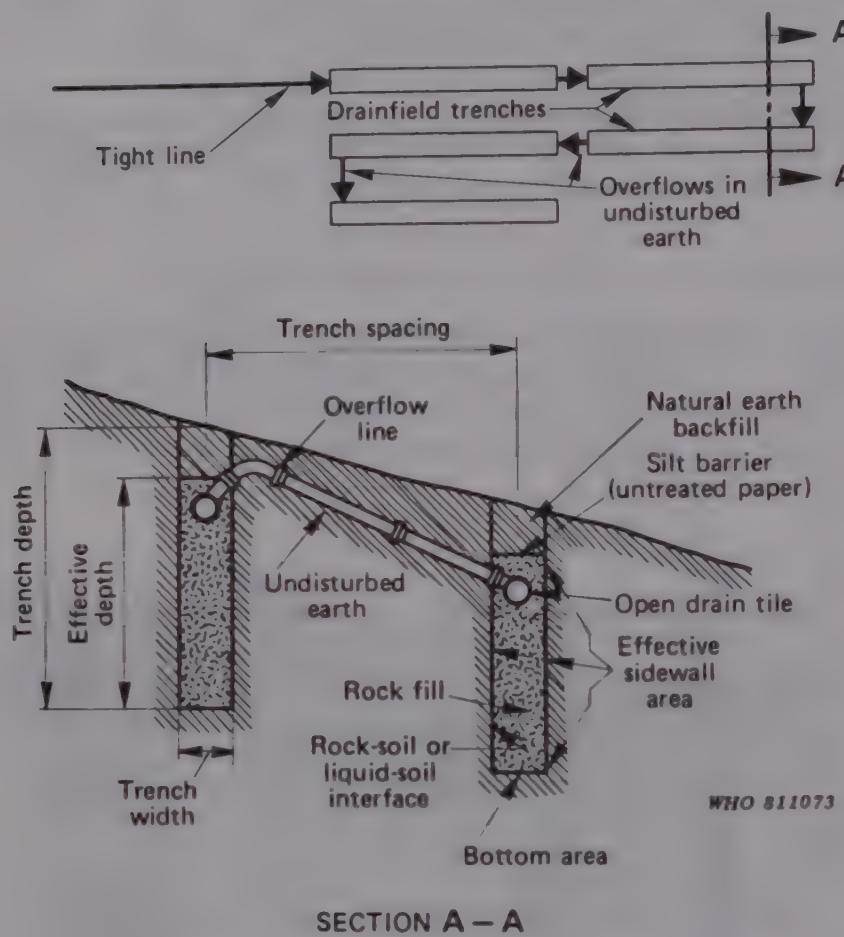


Fig. IIIE-4. A typical drainfield arrangement.
(Adapted from: Ross Bulletin No. 8, p.41)

The limiting factor in design is the rate at which water can seep into the soil (the "infiltration rate"). For disposal of sewage, it has been found that this rate, after the soil has become partially clogged with sewage, is roughly the same for most types of soil and ranges between 10-30 l/m² per day.^a For the disposal of spilt water, soil clogging will not be as serious as sewage; a figure of 20 l/m² per day would seem to be a reasonable assumption in calculating the length of trench required, using the following formula:

$$\text{Length of trench (m)} = \frac{\text{Waste water to be drained per day (litres/day)}}{\text{Effective trench depth (m)} \times 20 \times 2}$$

^a Laak, R. et al. Rational basis for septic tank system design. Ground water, 12 (1974)

The factor 2 on the bottom line allows for the use of both sides of the trench. The effective trench depth is the depth from the water level to the bottom of the trench. The bottom area of the trench is ignored in the calculation, because the important seepage is through the sides of the trench.

Although this formula can be applied to most kinds of soil, there are some soils into which water will soak only very slowly, so that soakage trenches cannot work. It is therefore useful to make infiltration tests of the soils in the area. A satisfactory test procedure is to drill at least three 150 mm diameter test holes, 0.5 m deep, across the proposed drainfield. These are filled with water and left overnight so that the soil becomes saturated. On the following day, they are filled to a depth of 0.3 m. After 30 and 90 minutes, the water levels are measured. The soil is considered to have a sufficient infiltration rate if the difference in the measured levels over the 60-minute period is at least 15 mm.

Plain-ended tile pipes or bell-and-spigot sewer pipes may be used. Pipe lengths are generally 300-600 mm. Both types of pipe are laid so as to leave gaps of 1-12 mm between the pipe lengths to allow the waste water to leak out. The trench bottom and the pipes in each trench should be laid level. When plain-ended pipes are used, the upper half of the joint must be covered with a strip of roofing felt or tarred paper, or a piece of broken pipe to prevent the entry of fine soils. The stones in the trench should be 20-50 mm size and should be covered by 300-500 mm of soil from the trench, over a protective layer of straw or untreated building paper.

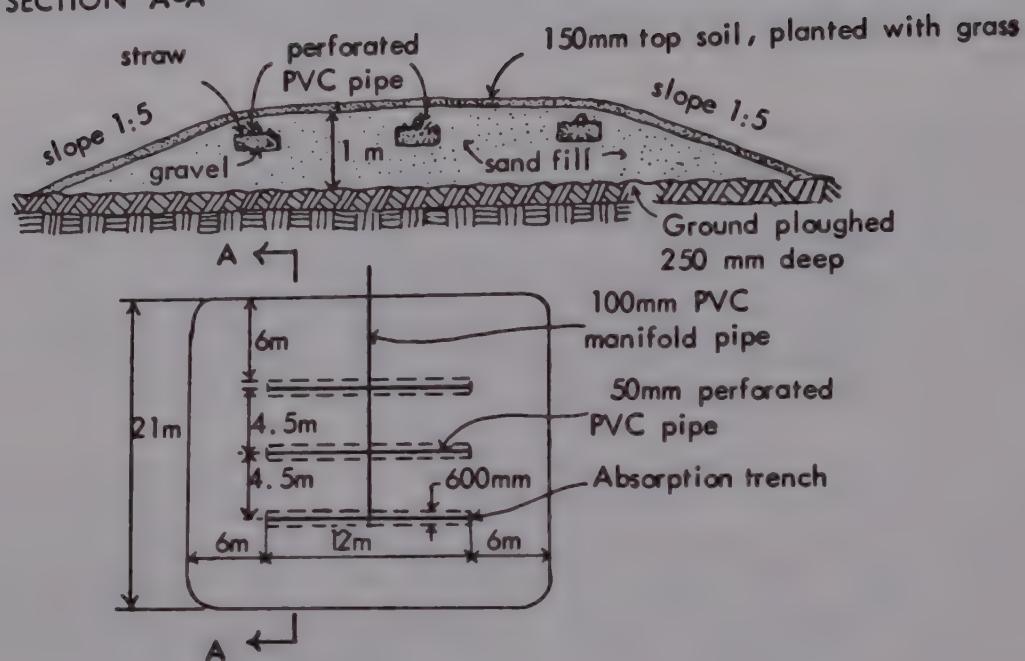
The flow of waste water should not be split up by distribution boxes. The trenches should be connected end-to-end so that, as each trench fills, the effluent overflows to the next one. Each trench should be level with, or below, the preceding ones. The soil cover in the area should have a minimum thickness of 1.5 m and the level of the seasonal high ground-water table should be not less than 0.6 m below the trench bottom.

3.3.3 Evapotranspiration bed or soakaway mound

Another version of the drainage field is the evapotranspiration bed (see Fig. IIIE-5). The waste water is distributed through open-joint pipes in the evapotranspiration bed which comprises a 200-500 mm depth of coarse sand and gravel underlying a 100 mm depth of topsoil planted with a fast-growing local grass. Grasses have high transpiration rates and the waste water is lost to the atmosphere by transpiration.

The size of evapotranspiration beds is calculated on the basis of the transpiration rate which is about 80% of the rate of evaporation from an exposed water surface, or on the basis of providing about 15 days' storage (during the rainy season) of the effluent in the sand layer, whichever gives the larger area. Evapotranspiration beds need very conscientious management if they are to work well. It is usually preferable to combine them with soakage trenches as shown in Fig. IIIE-6.

SECTION A-A



PLAN VIEW

Fig. IIIE-5. A prototype design for a soakaway mound, for use in areas where the water table or rock is near the surface.
(Adapted from: Ross Bulletin No. 8, p.43)

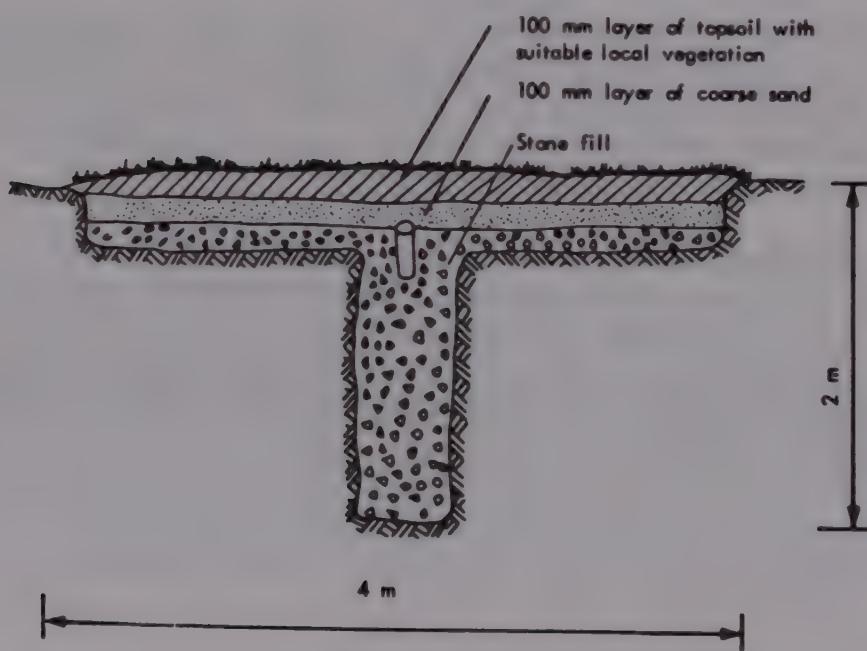


Fig. IIIE-6. A soakage trench combined with an evapotranspiration bed.
(Adapted from: Ross Bulletin No. 8, p.44)

4. Large-scale drainage works

Low-lying flat lands with insufficient permeability and inadequate natural drainage tend to retain water indefinitely and form marshes and swamps which are suitable habitats for many mosquito species. Land development agencies and enterprises will reclaim these lands when it is economically profitable to do so. In developing countries, where in general land is abundant and land reclamation involves large investments, swamps and marshes are usually left untouched. It is the responsibility of the health authority to stress the health risk presented by these situations and to exert its influence to induce the appropriate governmental departments to carry out the required works for eliminating or reducing the extent of these dangerous areas. Marshes and other large bodies of stagnant water may often be sources of fish, or of plant materials that can be used for house construction in rural areas. Before any drainage work for mosquito control is carried out, it is of primary importance that the use made of the water should be thoroughly investigated and that the proposed drainage should be acceptable to the population.

4.1 Coastal situations

Water that flows seawards usually loses its energy and velocity as it reaches the flatter slopes in the vicinity of the coast. River mouths are exposed to the inflow of sea-water provoked by tidal variations in level, and the direction of the river flow is regularly reversed for a variable distance upstream. The silt and debris carried by the river water tend to settle and form deltas, with intricate channels and lagoons which in time may turn into swamps and marshes. River silt and debris combine with beach and dune sands that have been displaced by sea waves to form bars at the mouth of streams and to block off extensive areas of lowlands, from which water can escape only by slow percolation across the beach barrier. Thus, along the shoreline, mosquito breeding may occur in the retained water of varying degrees of salinity, fed by rainwater, sewage, seepage and seawater.

Many of these situations can be made unfavourable for Anopheles mosquito breeding by varying the salinity of these brackish waters. This subject is dealt with in detail in Chapter IV. Environmental modification measures for mosquito control in coastal swamps are discussed below.

4.1.1 Diking and dewatering of coastal swamps

The treatment of coastal marshes and tide lands requires careful study. Some have firm bottoms of coral reef or clay, and in others the bottoms are composed of soft unconsolidated materials to a considerable depth. In the former case, satisfactory results may be expected from the exclusion of tide waters by diking or embankments. If tide gates are installed at the drain outlets, local runoff may be periodically removed by gravity or pumping. In the latter case, however, the unconsolidated material will shrink when drained and will lie below the water table, creating depressions that are more difficult to treat. Therefore, the drying of such grounds by diking and dewatering should neither be expected nor undertaken.

Fig. IIIE-7 shows an arrangement for diking and dewatering by gravity. It will be noted that the lagoon is isolated from the sea by strengthening and raising the natural sand barrier to a height that will prevent the overflow of sea water into the lagoon at high tides. Across the levee, suitably spaced pipe drains of appropriate size are laid with an even and adequate gradient to drain the lagoon water into the sea at low tides. The upper end of each drain is at a level near the bed of the lagoon and fitted with a suitably designed intake structure. The lower end of the drain is located slightly above the mean sea level and is equipped with a self-closing gate to prevent the entrance of sea water at high tides.

In general, the pipe drains of such arrangements should be extended to some distance into the sea and their outlets should be sufficiently above the sea bed to prevent the sand from clogging the flow. They should be properly anchored to protect them from wave action.

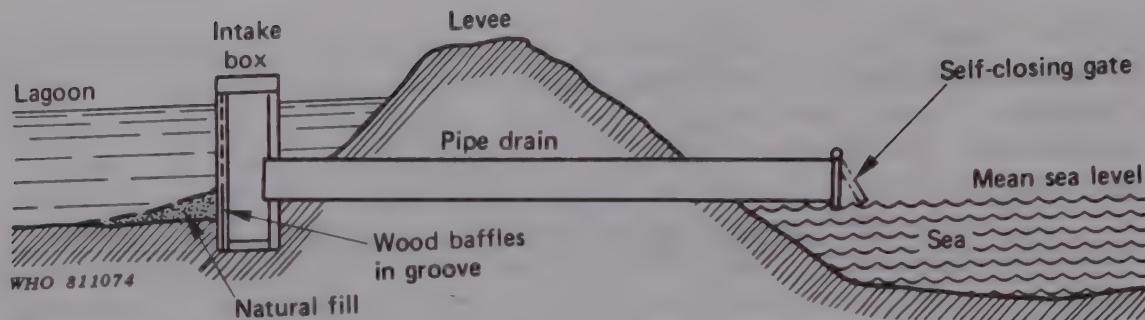


Fig. IIIE-7. Levee and disposal drain for gravity drainage of a lagoon into the sea.

Note the intake structure with concrete walls on three sides and the fourth side facing the lagoon left open. Grooves are provided on the edges of the fourth side of the intake so that wooden boards of 15-20 cm width can be slid in as required to adjust the sill height of the opening as the lagoon becomes naturally filled with silt. When the sediment reaches the top of the first board, a second one will be added, and so on. Thus the bed of the lagoon can be gradually raised without interfering with the drainage operation and without any silting of the drain.

If the lagoon bed is so low that dewatering by gravity will not produce satisfactory drainage, it will be necessary to use pumping. Subchapter IIIA, section 4.4, provides some additional information on diking and dewatering.

4.1.2 Open marsh ditching

For swamps with soft bottoms of unconsolidated materials, the object should be to permit free circulation of high tides on to the low areas and the drainage of water off the surface at low tides. The system of ditches installed should therefore reach all low points to prevent the retention of either rainwater or tide water. By providing efficient connexion with the sea in this way, the swamp water will be of a high salinity which is unfavourable for the breeding of most species of anopheline mosquitos. For the control of brackish water breeders, the system would have to depend largely upon predation by naturally occurring or introduced organisms or larvivorous fish. Therefore, the approach may not be suitable for areas where the major local vector is a brackish water breeder, since biological control by predation might not provide the desired degree of control.

One way of operating the ditch system is to connect low places or holes to each other and to a natural outlet; another is to install a parallel system with holes connected to the nearest ditch (see Fig. IIIE-8). Where convenient, soil from the ditches should be used to eliminate nearby holes by filling.

4.1.3 Clearing and maintaining open stream outlets

Small stream outlets can be cleared manually using hand tools. For clearing larger outlets, the use of equipment may prove to be more efficient and economical. Where the beaches and bars are composed mostly of shingle, an outlet depth of about 0.5 m below low water level would be adequate, and a bulldozer would be a suitable type of equipment for clearing the mouth and spreading away the excavated material. Where beaches and bars are largely composed of sandy materials, a greater outlet depth, say about 2 m below low water level, will be required to compensate for the more rapid silting of the channel. The clearing can be performed efficiently by dragline equipment or by floating dredges.

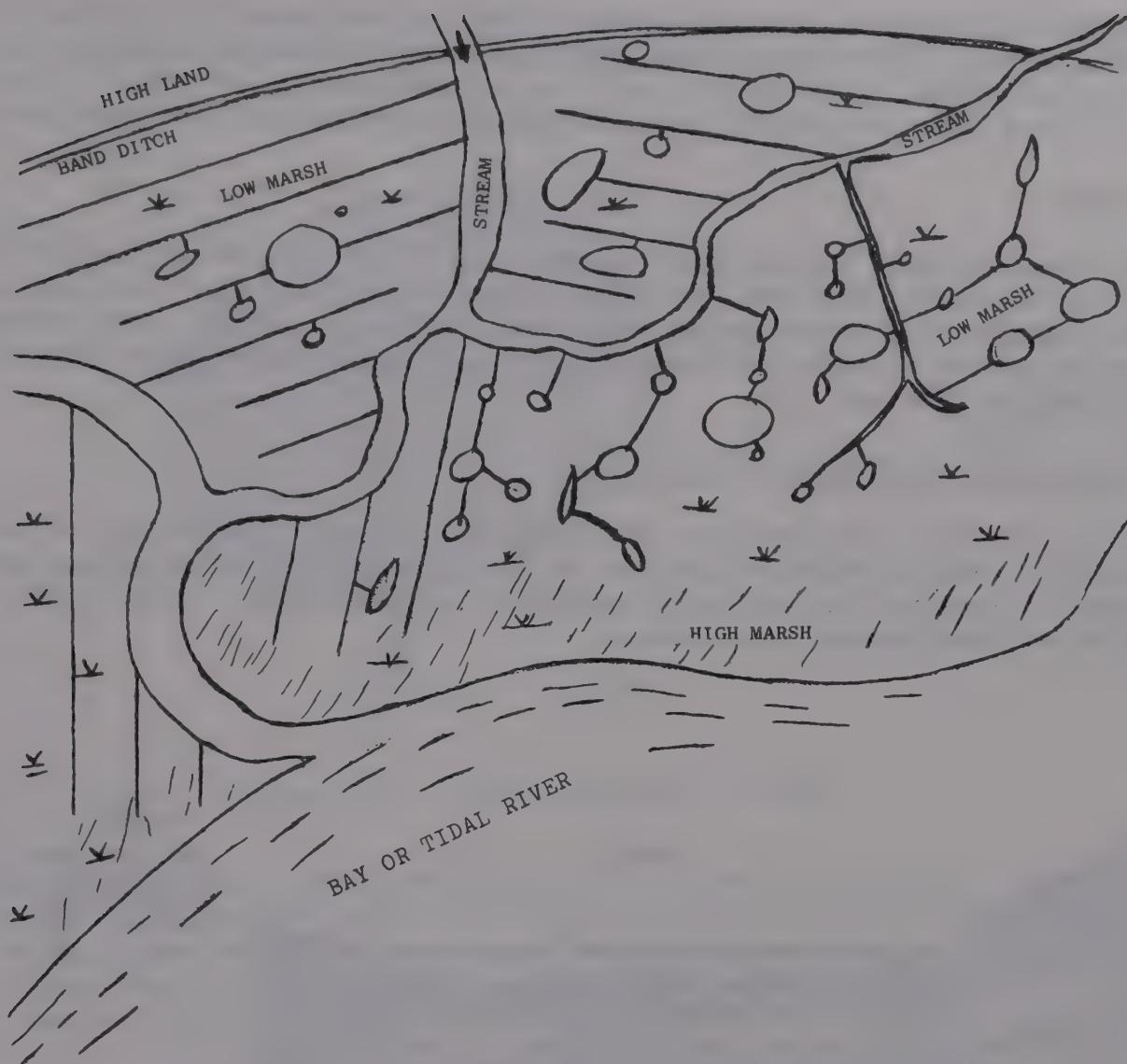


Fig. IIIE-8. Patterns of salt marsh ditching.

Parallel system, hole connecting system and combined system. Also illustrating intercepting band ditch at junction of marsh and upland.

It must be expected that the cleared outlets will sooner or later be reclosed through the same natural process that created the original blockage. The reclosing may be slowed down either by the construction of shore-perpendicular jetties at the flanks of the outlets in order to check along-shore sediment movements, or by the installation of jet or ejector pumps within the stream mouths which would automatically dredge out the accumulation of littoral materials. An alternative to stream mouth clearing is to connect the stream to the sea by inverted siphons that would exchange inland and ocean waters as a result of tidal action. However, all these methods are expensive and should not be applied unless they are economically justified and their effectiveness has been proved by pilot studies. Occasional dredging, whenever necessary, is still the usual method for maintaining stream outlets across sand bars. The mouth of a small stream may be reopened by flushing if water is available in adequate quantity for this purpose and if storage facilities can be constructed at a site of suitable elevation.

4.2 Inland situations

4.2.1 Swamps located in the vicinity of water bodies

Swamps on the flat edges of, or in areas adjacent to, lakes and ponds are due to over-saturation of the soil and insufficient slope for natural drainage. Suitable marginal

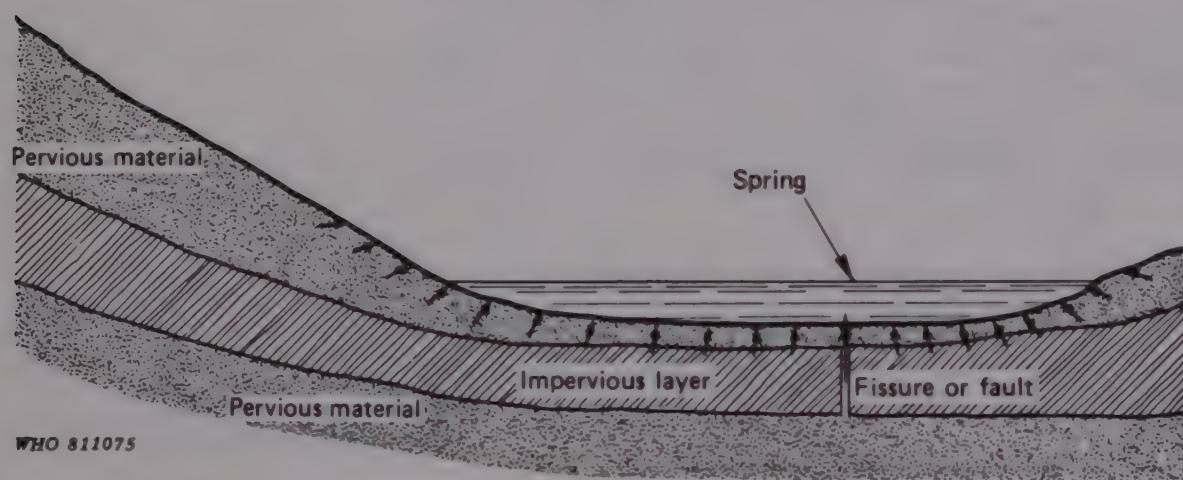
drainage connecting the swamp to the main body of water, if the topography permits, would provide a solution to such situations. In circumstances where marginal drainage alone is inefficient and uneconomical, recourse should be had to the measures described in subchapter IIIA, sections 4.3 and 4.4; or else to those described in subchapter IIIF, sections 6 and 7.

4.2.2 River swamps

Meandering rivers in flat valleys with a normal slow flow and much silting, but exposed to periodic torrential flows which break through the banks and flood the low-lying areas along the course, may form extensive river swamps which are difficult to drain. The problem of such river swamps can be solved or greatly alleviated by river channel improvement through methods described in subchapters IIIC and IIIF.

4.2.3 Swamps resulting from seepage or springs

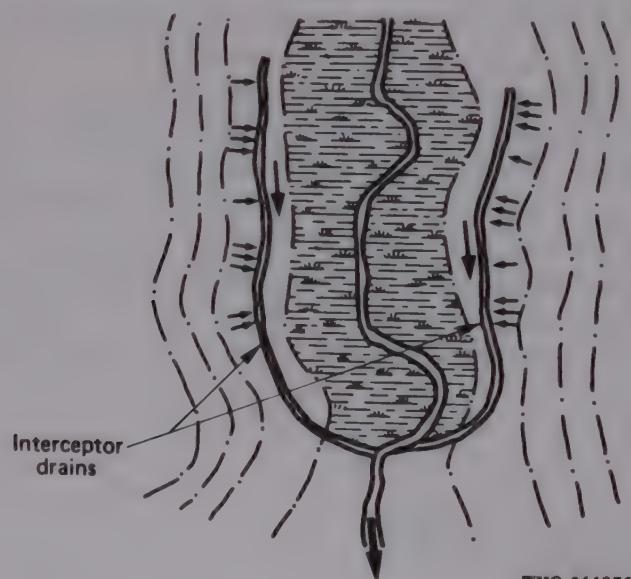
Swamps can be formed by the seepage of subsurface water and the discharge of springs. This type of swamp is usually found at the foot of rising ground where relief and geological conditions favour the flow to the surface of perched or confined water. Fig. IIIE-9 illustrates the conditions that produce such swamps.



(Adapted from: Home, H.
The engineer and the prevention of malaria.
London, Chapman & Hall,
1926, p.66)

Fig. IIIE-9. Conditions that produce a swamp fed by general seepage and spring discharge.

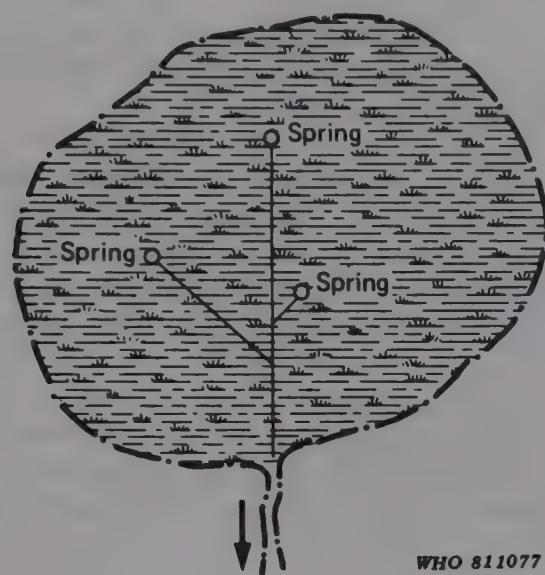
Fig. IIIE-10 shows a typical case of the formation of a narrow swamp at the bottom of a ravine by seepage from the hillsides. Suitably designed interceptor drains running parallel with the contour at the foothill will collect the seepage water, discharge it into the stream below the seepage area, and allow the swamp to dry up.



(Adapted from: Home, H.
The engineer and the prevention of malaria.
London, Chapman & Hall,
1926, p.66)

Fig. IIIE-10. A narrow swamp in a ravine due to seepage.

If the swamp is due to springs within its area, the springs have to be found and drained away from the swamp by appropriate means (see Fig. IIIE-11).



(Adapted from: Home, H.
The engineer and the
prevention of malaria.
London, Chapman & Hall,
1926, p.67)

Fig. IIIE-11. A swamp due to springs within its area.

Drainage outfall into a stream should enter the stream laterally with the current so that it can withstand floods and maintain stability. It should be borne in mind that the "shortest ditch" may be the worst located outfall as far as maintenance and stability are concerned. Fig. IIIE-12 shows the proper location (as well as the undesirable location) of the outfall into the stream, and the side slope protection at the junction point.

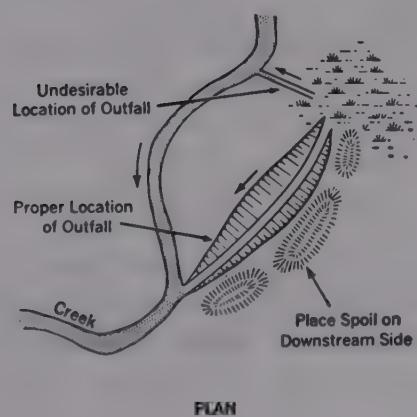
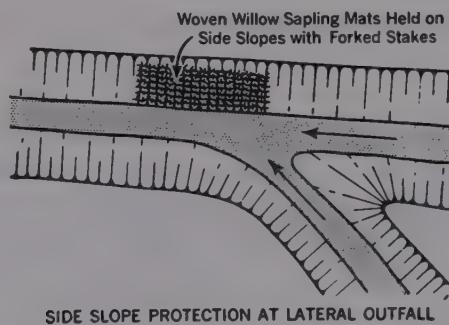


Fig. IIIE-12. Drainage outfall in flood plain creeks.
(Adapted from: Malaria control on impounded waters. Washington, DC, United States
Public Health Service, Tennessee Valley Authority, 1947, p.137).

4.3 Investigations and studies required for drainage works

The drainage of swamps is an effective measure of mosquito control and is of special interest in malarious regions. Two main principles govern the reclamation of swamp areas: the interruption of the supply of water that feeds the swamp; and the provision or improvement of the outlet carrying the swamp water away from the flooded area. No work should be started, however, before defining the problem and selecting the best solution. The required preliminary engineering investigations and studies include:

(a) The topographic survey of the flooded area and surrounding land needed for preparing a general map which should show contour lines at 0.5 m elevation intervals, below and above the water level. These data are essential to determine the volume of swamp water, the surface area covered by the swamp at various elevations, the depth of the lowest point to be dewatered, the location of a suitable outlet, the route of the ditches, and the earthwork involved.

(b) The investigation of the water source that supplies the swamp in order to determine whether it is surface water (rainfall and general runoff from neighbouring hills, well-defined streams, etc.) or subsurface water (seepage or springs), and to analyse the effect of the probable maximum and minimum flow on downstream water users as well as on downstream vector production.

(c) The investigation of the subsoil and, in particular, its permeability so as to determine the possibility of vertical drainage.

(d) The study of distances from population habitation, and work and recreation areas. This information is required in assessing the desirability of installing pipe or other closed conduits, or ditch liners, in the vicinity of human activities.

(e) The investigation of ways of dealing with the spoil. On some large projects, the spoil can be used advantageously either to fill the lowest points of the area to be drained, thereby lessening the required depth of the outlet channel, or to fill small locations which might otherwise require supplementary drains.

(f) The study of the environmental implications and the acceptability to the population of draining the swamp.

The topographic map will indicate whether an old channel exists on the bed of the swamp and will enable its course to be traced. The map may also suggest the existence of an old natural outlet that has been obstructed or is of insufficient capacity and depth. These findings should be confirmed by a more detailed survey along the presumed course and outlet site.

Based on the investigation of the water source, measures to intercept the waterflow into the swamp may be planned and designed. Such measures may include relocating or diverting streams so that they discharge out of the area, digging ditches and building levees along the foot of hills or at the periphery of the swamp to deflect surface and subsurface water, or tapping springs. Methods for the clearing and improvement of an existing outlet or the provision of new outlets are also worked out. Sometimes a number of alternatives are formulated so that the most economical in terms of execution and effectiveness may be selected.

The prevention of water entering the swamp and the release of water from it will gradually lower the water level. As the water recedes and the bed is exposed, seepage water is channelled towards the outlet. Once the swamp problem is under control, it may be possible to consider other reclamation measures such as natural land-fill if a supply of heavily silted water is available and can be readily diverted to the swamp area (see subchapter IIIF, section 5).

In situations where the swamp is formed on the lowest point of a closed valley, the gradient will be insufficient for the free discharge of swamp water through an outlet. An

exploration of the subsoil may indicate the feasibility of vertical drainage. Failing this, the possibility may be considered of drainage by pumping through a high-level outlet (if available) or a tunnelled outlet. In this way, the wet area can sometimes be reduced to a few deep trenches where mosquito production can be controlled by the use of biological agents or chemicals.

5. Methods for ditch excavation

Once the alignment and gradient of the ditch are established, a profile of the ground surface along the centre line is drawn to determine ditch depths and calculate excavation volumes.

Work in the field starts by locating the ditch centre line by driving pegs at regular intervals of 30 to 50 m. The pegs may have to be offset from the ditch centre line to facilitate excavation. A frame formed of a horizontal batten and two posts is fixed across the future channel at each point marked by a peg (see Fig. IIIE-13). The elevation of the horizontal batten is such that a stretched cord over a set of battens will produce a guideline above the ground, parallel to and at a fixed height over the channel bed. Excavation workers are provided with staffs, called grade rods, marked to show the standard distance between the cord and channel bed. The staff is responsible for the periodical checking of the excavation depth. The cord can be removed so that it does not interfere with the work and is only stretched when required for checking. As the accuracy of the work depends on the proper levelling of the horizontal battens, great care should be paid to this in order to obtain precise results.

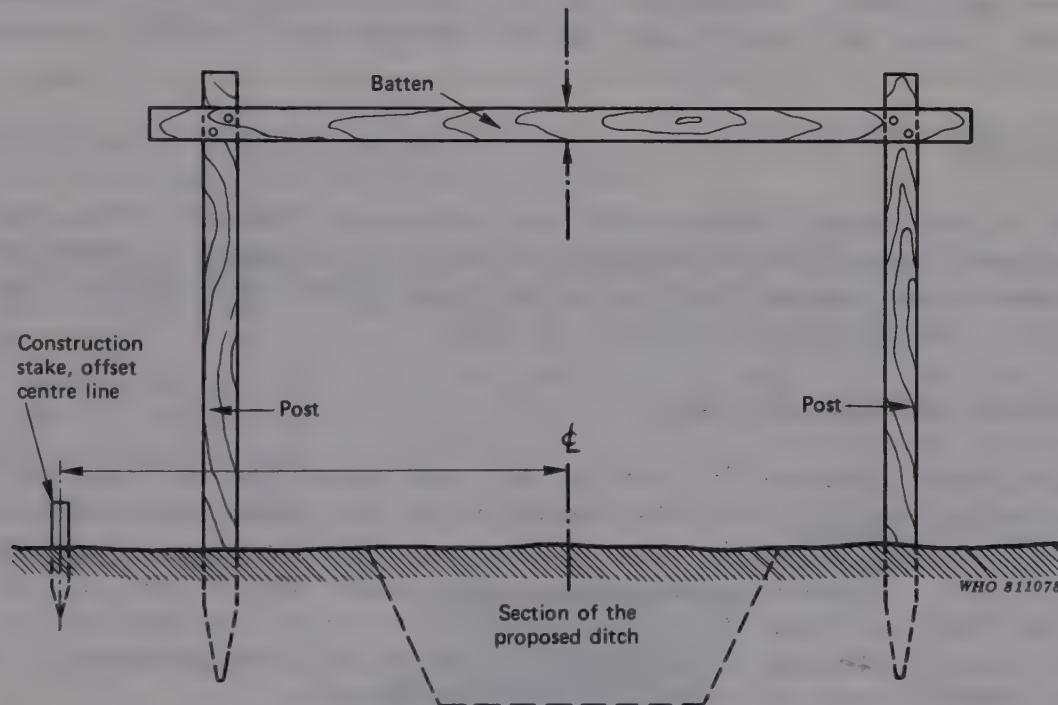


Fig. IIIE-13. Guiding frame for alignment and depth of ditches.

5.1 Hand-excavated ditches

In the rural areas of developing countries, manual labour is usually available for excavation work. Manual excavation can produce good and cheap results if the labour force is disciplined and well organized. The work is rather slow and can be difficult if the substrata are hard and rocky; excavating machines and explosives may have to be brought in to loosen such materials.

Excavation by hand is suitable for small and medium ditches; the width of trapezoidal ditches may range from 0.3 to 2.5 m. For wider ditches, machinery is indicated although hand excavation can reach depths of 6-7 m using the "bench technique". With a pick and shovel, an experienced labourer can dig about 2 m^3 daily in lightly compacted soils (sandy loams, loams) at shallow depths, not exceeding 1 m. At greater depths, output drops rapidly and at depths

over 1.5 m, staged excavation with a second lift (or more) is needed to bring the spoil to the surface. Additional labour is needed for loading and carting the spoil. These figures are valid for a strong and experienced worker. With other labourers, less than 50 % of this output may be achieved.

5.2 Machine-excavated ditches

Machine excavation is becoming more common in developing countries despite the heavy initial costs and high price of fuel. The most obvious advantage is its efficiency and rapidity. Less obvious but equally beneficial are the savings in food and lodging, direction and control of workers, and supervision and administration of the work.

The larger ditches, between 3 and 30 m bottom width, are dug by equipment that may include power shovels, cranes and trench excavators; ploughs and scrapers are also used. The choice of heavy equipment for excavation largely depends on the size of the project, type of soil, cost of moving the equipment to the operation site, availability of skilful operators, and maintenance.

In general a power crane with a dragline bucket is most suitable for long stretches of ditches. Trenching machines greatly simplify the cutting of side slopes, and tractor-drawn ploughs and scrapers can be used economically to cut shallow ditches in soft ground.

Before starting earth excavation, whether by hand or machine, the ground should be cleared of dense vegetation, trees and rocks. Vegetation can be cut mechanically with mowers, burned, or killed with herbicides; rocks and tree stumps can be removed with winches, tractors or explosives.

5.3 Ditching with explosives

The main advantages of excavating ditches with explosives are reduced costs, rapid completion of the task, no overhead expense for equipment, no need for disposal of excavated material, simplicity in operation, suitability for conditions where other methods are difficult to apply, and versatility in the size of ditches to be dug.

Two methods are used for blasting ditches:

(a) The propagation method consists in priming only one cartridge in a set or line of charged holes. The concussion produced from the explosion of the primed cartridge is propagated through the earth and sets off the whole line of charges. The priming may be done electrically or by a time fuse. Adequate propagation takes place only in wet soils; when the soil can be moulded in the hands so that it sticks together in a ball, it usually contains enough moisture for this method. In less moist soils, blasting by propagation will require shorter distances between charges and will therefore be less cheap.

(b) The electrical method consists of inserting an electric blasting cap in every charge, connecting it to an electric circuit either in series or parallel, and detonating the whole set simultaneously by means of a blasting machine. It is more expensive than the propagation method because of the cost of wire, blasting caps, etc., and takes longer to prepare, but it can be employed in any type of ground except dry loose sand, in which it is practically impossible to blast ditches.

For blasting shallow ditches the two most common patterns for placing the dynamite charges are:

(a) A single line of holes, spaced at equal intervals along the centre line of the proposed ditch. The depth of the charge depends on the wetness and looseness of the soil material. In general, the wetter and looser the soil, the closer to the surface the dynamite cartridge should be placed for best results. A good rule of thumb is that the top of the uppermost cartridge in a hole should never be more than 30 cm under the surface. Where the

ground is extremely soft and wet, 10 cm under the surface is sufficient. Table IIIE-1 gives general specifications for the single-line pattern of loads.

Table IIIE-1. Specification for single-line pattern of loads
(Adapted from: Ditching with dynamite. Wilmington, DE, 1955).

Cartridges per hole	Depth to top of charge (m)	Depth of ditch (m)	Top width of ditch (m)	Distance between holes (m)	Dynamite required (kg/100 m)
$\frac{1}{2}$	0.15-0.20	0.45-0.60	1.2-1.5	0.30	37.5
1	0.15-0.30	0.75-0.90	1.8	0.38	60
2	0.15-0.30	0.90-1.0	2.4	0.45	100
3	0.15-0.30	1.2-1.4	3.0	0.53	130
4	0.15-0.30	1.5-1.7	3.9	0.61	100
5	0.15-0.30	1.8-2.0	4.8	0.61	188

The cartridge referred to in this table is one with an approximate weight of 0.23 kg containing 50 % straight nitroglycerin dynamite.

(b) The cross-section pattern is designed for wide, shallow ditches. It consists of a centre line of holes, as in the single-line pattern, with perpendicular cross rows located at every other hole of the centre line. Fig. IIIE-14 indicates the plan to be followed when loading one cartridge per hole at 38 cm spacing; if more than one cartridge per hole is required, refer to Table IIIE-2 which gives the specifications for the same general pattern with a variation in distances between holes on the centre line and between holes in the cross rows.

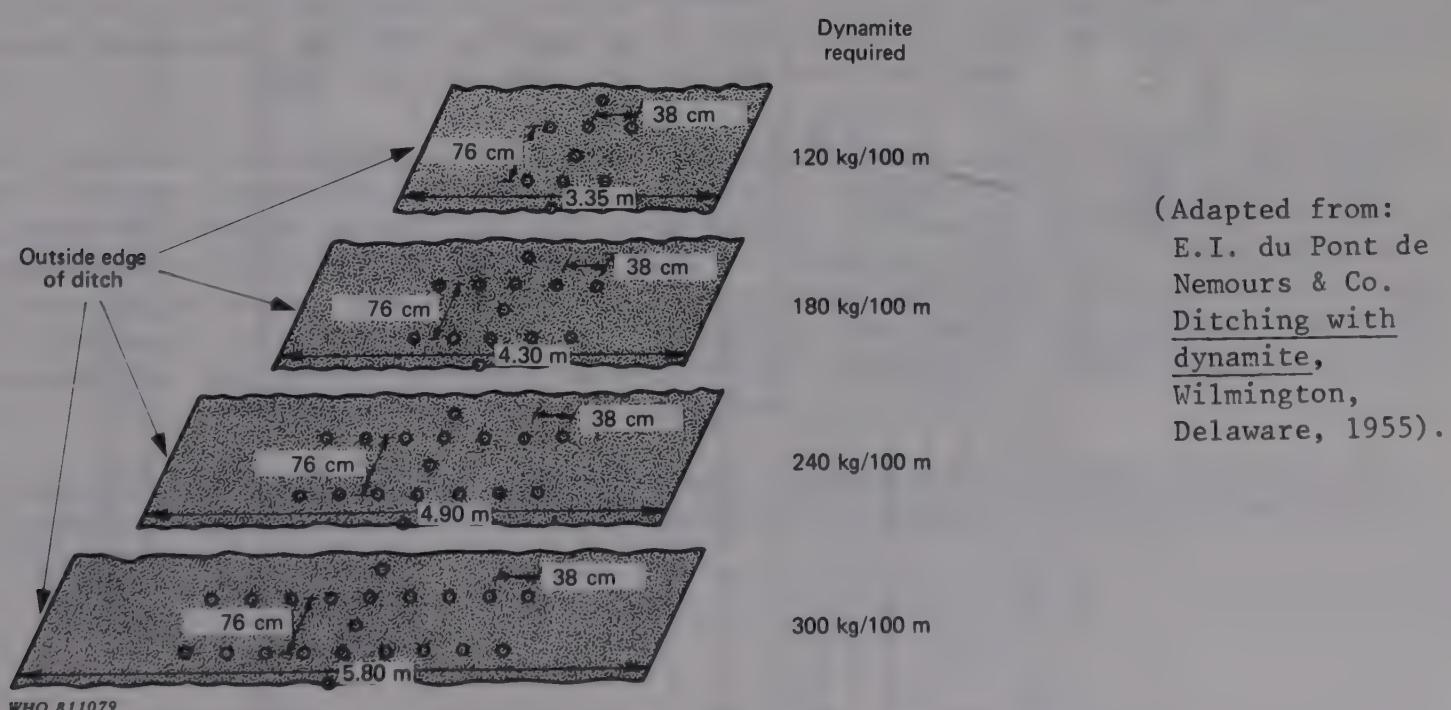


Fig. IIIE-14. Ditching with dynamite. (1) The cross-section loading pattern — one cartridge per hole, 38 cm spacing, depth of ditch 0.76 to 0.91 m.

Table IIIE-2. Specifications for cross-section pattern of loads.
 (Adapted from: Ditching with dynamite. Wilmington, DE, 1955).

Cartridges per hole	2	3	4	5
Distances between holes (m)	0.46	0.53	0.61	0.61
Distances between cross rows (m)	0.92	1.06	1.46	1.22
Depth of ditch (m)	0.9-1.05	1.2-1.35	1.5-1.65	1.8-1.95
Number of holes per cross row	Width (m)	Dynamite (kg/100 m)	Width (m)	Dynamite (kg/100 m)
3	3.35	200	3.95	258
5	4.25	300	5.20	376
7	5.20	400	6.10	515
9	6.40	500	7.30	644
11	7.30	600	8.20	771

Width (m)	Dynamite (kg/100 m)	Width (m)	Dynamite (kg/100 m)
3	200	3.95	258
5	300	5.20	376
7	400	6.10	515
9	500	7.30	644
11	600	8.20	771

The cartridge referred to in this Table is one with an approximate weight of 0.23 kg containing 50% straight nitroglycerin dynamite.

Both the diagram and the Table are relevant to wet, soft soil conditions which are most favourable to propagation. Variations in results may be expected in different conditions and test shots should be run to determine the best loading plan.

All holes should be bored to the bed level of the proposed ditch or slightly above it; in uneven ground, the holes will therefore be bored to different depths. More cartridges should go in the deeper holes (see Fig. IIIE-15). The holes should be vertical and in a straight alignment.

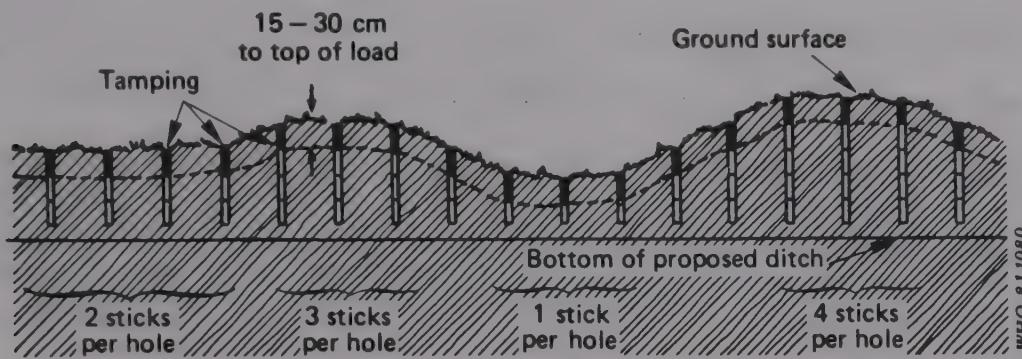


Fig. IIIE-15. Ditching with dynamite. (2) When the ground surface varies, the load is modified to maintain the bottom of the ditch at the required level.

(Adapted from: E.I. du Pont de Nemours & Co. Ditching with dynamite, Wilmington, Delaware, 1955).

5.4 Precautions during blasting

Experience shows that blasting methods for ditching can be as safe as any other method provided that workers are properly trained and that the instructions on the handling and use of explosives issued by the manufacturers and by safety councils are strictly followed. Accidents and injuries from explosives are too often caused by workmen ignoring safety practices. A study on such accidents in mining pits and quarries, in logging, construction and tunnelling operations, in agriculture, and in the petroleum industry, indicates that about 74 % of the injuries occurred during blasting, 12 % occurred before blasting (i.e., loading accidents), and 14 % occurred after blasting. All the workers injured during blasting either took poor shelter or took no shelter at all, or stayed too close to the scene of blasting. A flying rock can break a skull at a distance of 100 m. Ricocheting rocks may come from any direction; it is not enough to take cover facing the blasting scene.

The supervisor is responsible for the safety of the men. He should plan each job with safety well in mind, choose his men carefully, and train them properly; they should know about the hazards of their job and the precautions to be taken. The supervisor should see that adequate shelters are provided and make sure that the workers use them. Wherever shelters cannot be provided he should see that workers are protected by natural barriers or that they leave the blasting area in time. He is also responsible for the storage, transport and handling of explosives. He should supervise storage facilities, vehicles, and loading and firing equipment so that everything is kept in good condition.

In certain countries, the use of explosives is restricted for security reasons and blasting operations may have to be carried out with the consent and under the supervision of an army or police representative.

1006

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IIIF. LAND FILLING AND GRADING

Contents

	<u>Page</u>
1. Introduction	102
2. Land filling and grading for agriculture	102
3. Small fills for mosquito control	103
4. Sanitary land fill	104
5. Land shaping	104
6. Natural fills	105
7. Large hydraulic fill	105

1. Introduction

Filling of small holes, pits, ponds and other similar water pockets in and around villages is a simple and effective means of mosquito source reduction and has been used in malaria control programmes with good results. Land filling and grading for agricultural purposes can help in mosquito control by eliminating shallow topographic depressions and low spots on farm lands which, when filled with rain and irrigation water, create habitats for mosquitos.

2. Land filling and grading for agriculture

Land filling and grading for agriculture consist in correcting irregularities of the land surface with a view to improved irrigation. It is an essential practice prior to the application of surface irrigation methods which depend on the rapid and even distribution of water over the land. Within certain limits, land filling and grading can be useful in correcting depth differences in the fertile topsoil, flattening steep slopes and improving drainage.

Land filling and grading may be impractical and uneconomical where the soil is excessively permeable and high discharges are needed to overcome losses by percolation, where the topsoil is very shallow and cutting will bring unsuitable soils to the surface, where the roughness of the topography demands large quantities of earthwork, where the land is too steep and the resulting grades will not ensure suitable water distribution or protection against erosion, and where the land is so flat and low that drainage is already difficult, although this depends on the feasibility of introducing pumped drainage. Where land to be irrigated cannot be economically improved by land filling and grading, the solution may be in sprinkler irrigation or some form of localized irrigation.

Where possible, it is advisable to remove all vegetation, including trees and brushwood, before earth moving starts. Medium to large-scale filling and grading operations are better carried out by mechanical equipment. The job is to scrape rather than excavate the ground, and machinery cannot be surpassed for this. Where available, animal-drawn scrapers may be more practical and economical.

An overall survey of the land is needed before preparing a land-forming plan for the entire farm. The actual filling and grading work is usually carried out over several years, a defined area being completed each year, because of financial and time limitations. The

final grades of land should be uniform, without depressions or low areas, to facilitate irrigation. The services of an engineer are required to handle the technical aspects of the entire filling and grading job, including the detailed survey and complete set of plans, setting stakes to indicate cuts and fills, inspecting and checking the progress of the work, and giving final approval of the finished job.

3. Small fills for mosquito control

For mosquito control the size of the area to be filled and graded is of secondary importance; the breeding potential is not directly related to the extent of the habitat. Mosquito production may be more active in an unused ditch than in a reservoir or lake, and more dangerous if located nearer to human settlements.

In malaria endemic areas, filling operations should be directed to large and small depressions, excavations, and holes (located in and around villages) which may hold water and serve as habitat for mosquito larvae. Borrow pits, abandoned ditches, waterholes and unused wells come into this category. They attract little public attention and the health official is perhaps the only person interested in their elimination.

Most of these depressions and holes can be filled without the need of engineering skill. Suitable waste materials are often available for filling small depressions. Otherwise, the earth needed for filling should be taken from ground where there is a sharp change of slope or from steep land. In fact, very steep land exposed to erosion can be improved by flattening part of it. In very flat lands, the removal of top earth, in such a way that a greater slope will result, will improve the natural drainage towards an existing stream or ditch. Fig. IIIF-1 shows the various situations suitable for excavating material for land filling.

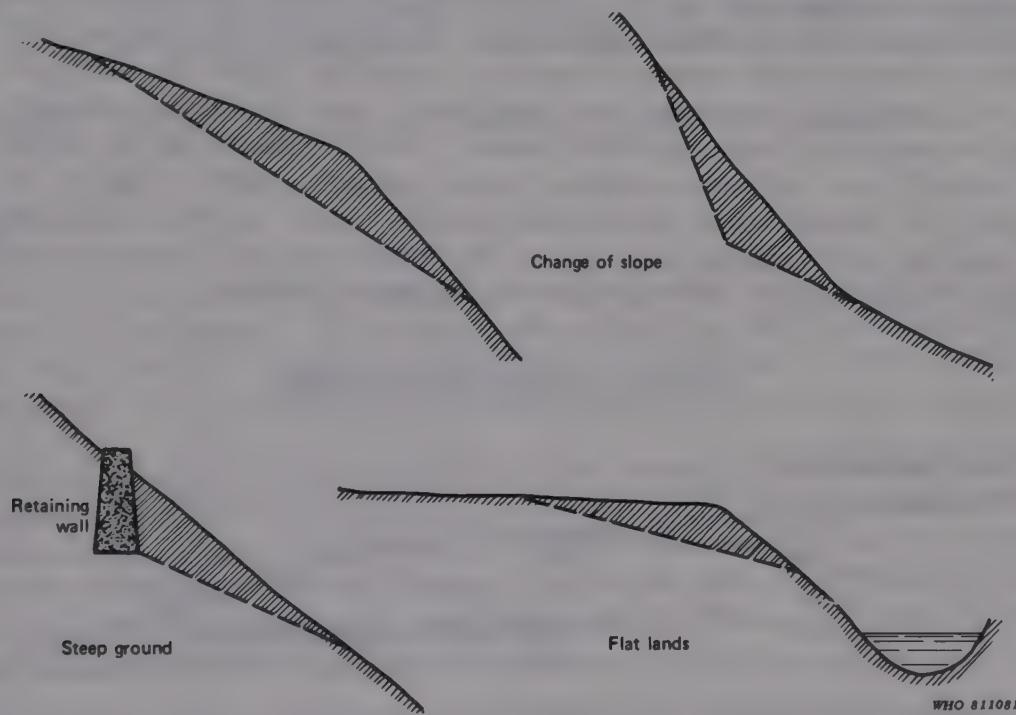


Fig. IIIF-1. Different situations where filling material can be obtained without risk of producing mosquito habitats.

Hand tools such as shovels, picks and wheelbarrows are sufficient for filling small areas; simple animal-drawn scrapers and carts can be used for larger areas. The tractor has become a familiar feature on agricultural land in most of the developing countries. Farmers, road contractors, public works departments, or mining and industrial enterprises can be asked to provide a piece of equipment and driver for a few hours when not otherwise employed.

Fills, whether large or small, should always be graded in the direction of the general ground slope so that water will run off without impediment; as the fill settles, more earth should be added until the desired grade is established. When the depression goes below the

ground water table and water is always present, the filling should be started at the upslope end so that, as the filling proceeds, the water is pushed ahead towards the natural outlet.

Although small land filling is a relatively simple operation, it is preferable to avoid the creation of holes or pits in the course of engineering activities. Borrow pits are an example of this problem which can reach considerable proportions. Road authorities should be aware of the health implications of borrow pits and should not permit them to remain undrained.

4. Sanitary land fill

Sanitary land fill is a method used both for refuse disposal and for land reclamation. The method consists in dumping a layer of refuse on a selected site and placing an earth cover on it each day after compaction. The land reclaimed can be used as a site for parks, recreational areas and outdoor storage.

Small to medium-sized depressions where water may collect and remain stagnant for periods longer than 10-14 days, thus creating mosquito breeding problems, may be eliminated by this method. However, filling must be carried out in strict accordance with the recommended practice of sanitary land fill, i.e., the daily placing of an earth cover on the refuse in order to prevent odour and unsightliness, and to avoid the breeding of flies and the harbouring of rodents in the dumps.

5. Land shaping

Where insufficient filling material is available for proper grading or where the cost of the earthwork involved is prohibitive, land shaping may offer an alternative solution. Its purpose is to smooth out roughnesses in the topography, without any major alteration except for what is needed to improve the surface drainage. Although land shaping may not produce the even and continuous slopes that result from land grading which is required for good surface irrigation, it generally improves the topography and surface drainage, with the elimination of holes or pockets that may hold water. It is therefore an effective measure for mosquito control. In hilly or rolling country, where proper grading cannot be economically justified, land shaping is therefore a good alternative. Fig. IIIF-2 illustrates the difference between shaping and grading and shows the same original surface profile, as shaped for drainage (on top) and as graded for surface irrigation (below).

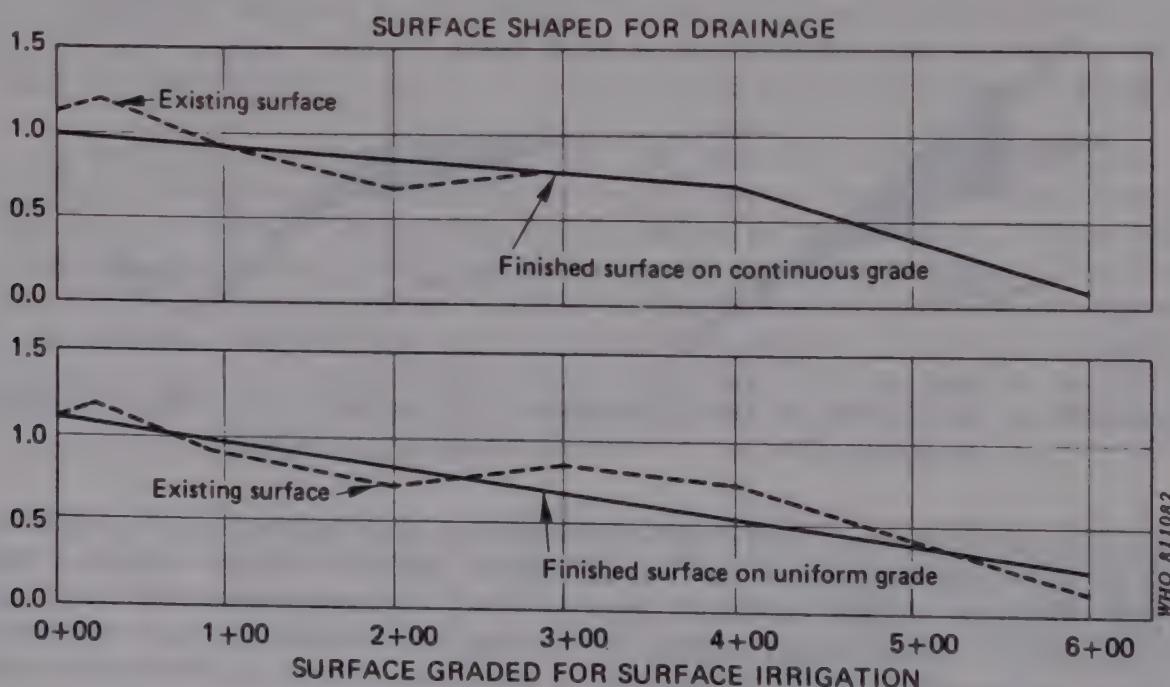


Fig. IIIF-2. Comparative profiles of a land surface, as shaped for drainage (on top) and as graded for irrigation (below).

Land shaping can also be suitable for draining flat lands where a slope is required. Parallel ditches are dug in the direction of maximum slope; the excavated material is used for forming either a convex surface between the two ditches with the vertex of the curve running midway and parallel to the ditches, or a continuous grade between ditches with the lower end on the edge of one ditch and the higher end on the edge of the next ditch (see Fig. IIIF-3). The spacing and size of the ditches are dictated by the volume of filling required. This shaping is particularly suitable where the ground water table is not close to the surface, as in that case the ditches might have to be dug deeper than would otherwise be required.

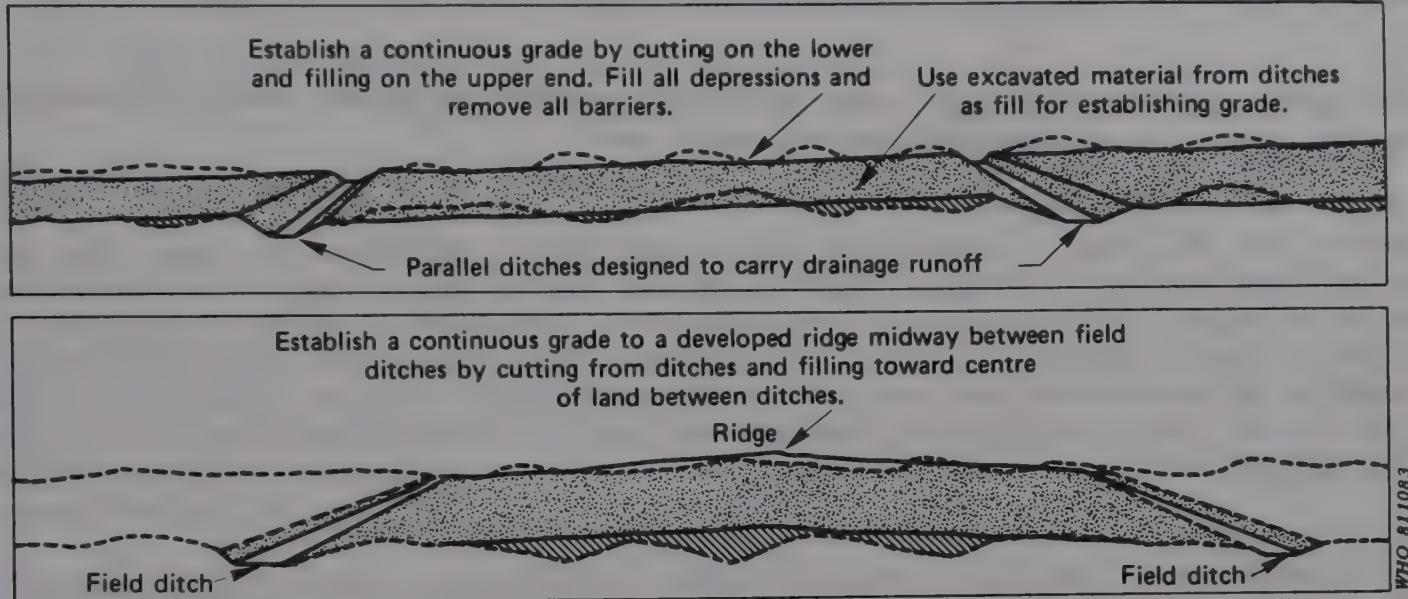


Fig. IIIF-3. Methods of grading land surfaces for drainage.

6. Natural fills

Where rainfall is intense and frequent, runoff flowing into ditches and streams carries heavy concentrations of sediment. By appropriate planning, this sediment can be trapped, allowed to settle, and used as a filling material to eliminate in due course a swamp or intermittently flooded area.

To facilitate the natural filling process, the outlet of the swamp or the low area is provided with temporary gates, weirs, levees or other structures to regulate the outflow so that the whole depression works as a settling basin. The stream carrying the sediment-laden water is diverted to discharge into the swamp just above the low point of the area to be filled; the incoming water spreads out and loses its initial velocity so that the sediment may settle on the bed and gradually fill the swamp.

The elevation of the outlet structure should not be higher than the final elevation of the desired filling. A V-shaped weir at the outlet will allow the discharge of the increased outflow resulting from the filling of the swamp and raising of the water surface level, without interrupting the silting action.

7. Large hydraulic fill

Where hydraulic dredging takes place in the vicinity, the method of large hydraulic fill offers a means of disposing of the dredged material by using it for filling. It is suitable for the filling of very large areas, particularly those adjacent to a river course, navigation channel or sea coast, at a very low additional cost.

Suction dredges are supplied with centrifugal pumps specifically designed to pump

slurries containing 10-15% solids by weight. The solids range from fine and coarse sediments to gravel and cobbles. Large volumes of water and sediment are moved by such dredging. During operation, a floating discharge and disposal line connect the dredge to the shore.

Large hydraulic fill projects are rarely attempted solely for malaria or mosquito control, but when such a project is implemented in connexion with the dredging of a river or harbour, arrangements may sometimes be made to have the soil deposited so as to eliminate a large source of Anopheles mosquitos. Many projects of this type have been implemented. An outstanding example is the disposal of dredgings from the Panama Canal, which eliminated thousands of acres of Anopheles breeding places that would otherwise have been difficult to control.

In the disposal of dredgings, caution should be taken to prevent mosquito breeding in the cracks that appear as the dredged material dries out.

IIIG. SETTLEMENT OF POPULATION AND PROTECTION OF WORK FORCE

Contents

Page

1. Resettlement and settlement of population	107
2. Protection of work force during construction	107
3. Antimalaria measures for immigration areas	108

1. Resettlement and settlement of population

Major environmental management works such as the impoundment of water and the system of water conveyance for irrigation are always associated with the moving and settlement of populations. The people living in the basin of the proposed reservoir need to be resettled and the immigrant population that moves in for permanent or seasonal settlement needs attention and help. Accommodation for both these groups must be planned and constructed in advance. Furthermore, the labour force brought in for the construction of works as well as the settled or resettled population needs to be protected against the health risks of the project area (see section 2 below).

The pattern of settlement to be adopted, either grouped (villages) or ungrouped (scattered houses), depends on the tradition and cultural background of the population concerned. In general, it is easier to provide facilities and services in the village type of settlement and to protect it against malaria and other vector-borne diseases. Environmental management operations for mosquito control need to be carried out only around villages, whereas in scattered settlement situations the operational coverage must be much wider in extent. Changing the pattern of settlement may have many social and cultural implications; nevertheless, the grouped settlement pattern has great advantages and, wherever not adopted, deserves serious consideration.

In any resettlement or settlement project, site selection is the primary consideration. Settlements should be located as far away from mosquito sources as possible. Sanitary facilities of a standard that ensures protection against disease transmission should be provided. The provision of drainage ditches to get rid of rainwater and of proper drainage for each water point (handpump, standpost, etc.) to remove spilt and waste water is an important measure for reducing mosquito sources.

Apart from the above-mentioned environmental management measures which are of a permanent nature and have relatively slow but long-lasting effects, it may be necessary to undertake measures to provide immediate protection. These may include medical screening of new arrivals, treatment of detected cases and chemoprophylaxis, spraying of houses with residual insecticides, mosquito proofing of houses, and other methods as discussed in Chapter V. It must be remembered that the establishment of an effective health service, including a primary health care network, is the most basic requirement for the protection of human health and should be given priority in any resettlement or settlement undertaking.

2. Protection of work force during construction

Water resource projects and other development projects require groups of workers assembled at construction sites. This situation is liable to produce epidemics of communicable diseases, particularly those transmitted by vectors. Newly arrived workers may have previously been exposed to different infections and some may even harbour disease agents. Measures need to be taken to prevent the spread of disease.

The work force is usually provided with health care and housing by the construction firms. The latter should be reminded that the sites for the required living quarters and field offices should be properly selected and that adequate sanitary facilities should be provided. The local health authorities or the government department responsible for the project should reserve the right to review construction camp plans and to inspect arrangements for water supply, liquid and solid wastes disposal, and sanitation of bath houses, bunk houses, the mess hall and kitchen. For the health protection of the work force, the same measures need to be taken as described in section 1 above for new settlers.

Experience has shown that in addition to the "official" work force, there is usually a large influx of work seekers, traders, etc. These unsupervised immigrants pose a real health threat, during both the construction and the operational phases of the project, in an area formerly uninhabited and hence totally devoid of facilities. It is important for this problem to be planned for in advance. Some sort of control over the movement of population into the construction areas may prove useful.

3. Antimalaria measures for immigration areas

Detailed suggestions on antimalaria measures to protect the work force in the project areas and the general population in new settlement areas are given in Manual on Personal and Community Protection against Malaria.^a A summary tabulation of suggested measures, included in that manual as an annex, is reproduced on the next page.

In connexion with the table, the following points are to be noted:

(i) The measures suggested for countries with a malaria eradication programme differ from those for countries with a simple malaria control programme only in the great importance given to surveillance in the former countries.

(ii) Please note the following values. Hypoendemic: spleen rate <10%. Highly dangerous: spleen rate 11-30%. Extremely dangerous: spleen rate >30%.

(iii) The scheme of antimalaria measures suggested for application in various malariogenic situations envisages a higher degree of malaria transmission than would be expected in non-immigrant populations; therefore, it may be too demanding. Also, the sharp distinction between "high-danger" and "extreme danger" zones on the basis of spleen rate only is too artificial. The responsible epidemiologist should therefore use his discretion to decide whether, under the local circumstances, a less aggressive approach can be adopted without risk.

^a WHO Offset Publication, No. 10, 1974, p.38.

SUMMARY OF MEASURES ADVISED FOR IMMIGRATION AREAS^a

		Residual spraying	Screening of newcomers	Compulsory fever reporting	Health education and malaria briefing	One additional spraying cycle	Mass treatment at each spray round	Immediate spraying of new houses	Moving to consolidation phase permissible	Surveillance ^b	Mass drug prophylaxis	Larval control	Drug administration as main antimalaria measure	Screening of houses with wire net
WITH A MALARIA ERADICATION PROGRAMME														
A. Planned development projects		Normal attack phase operations applied with high efficiency and strict supervision	+ + + if possible	+ + +	+ + +	+ + +	+ + +	yes ^c no no	PCD FS(7) FS(2)	a	a'			(+) ^d
Hypoendemicity														
High danger zone														
Extreme danger zone														
If indigenous cases still persist, supplement with:														
B. New settlements														
Hypoendemicity														
High danger zone														
Extreme danger zone														
If indigenous cases still persist, supplement with:														
WITH NO MALARIA ERADICATION PROGRAMME BUT WITH A MALARIA CONTROL ORGANIZATION		Residual house-spraying as in other highly malarious areas under control	+ + + if possible	+ + +	+ + +	+ + +	+ + +	yes ^c no no	PCD FS(3) FS(2)	a	a'			(+) ^d
C. Planned development projects														
Hypoendemicity														
High danger zone														
Extreme danger zone														
If numerous new cases still occur, supplement with:														
D. New settlements														
Hypoendemicity														
High danger zone														
Extreme danger zone														
If numerous new cases still occur, supplement with:														
WITHOUT A MALARIA CONTROL ORGANIZATION														
E. Planned development projects														
Major projects														
Minor projects														
F. New settlements														
		<p>^a + - obligatory; (+) - optional; a, a' - alternatives.</p> <p>^b FS - full surveillance (during first year of attack; however, epidemiological investigation of cases or foci is dropped); PCD - passive case detection; S - search for fever cases in labourers' quarters. Figures in parentheses indicate intervals (days) between house-visiting in active case detection.</p> <p>^c Provided screening of newcomers is maintained as long as immigration continues.</p> <p>^d Measure for non-immunes only.</p>												

^a + - obligatory; (+) - optional; a, a' - alternatives.

^b FS - full surveillance (during first year of attack; however, epidemiological investigation of cases or foci is dropped); PCD - passive case detection; S - search for fever cases in labourers' quarters. Figures in parentheses indicate intervals (days) between house-visiting in active case detection.

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^d Measure for non-immunes only.

IIIH. EQUIPMENT FOR ENVIRONMENTAL MANAGEMENT

Contents

	<u>Page</u>
1. Introduction	110
2. Justification for the use of equipment in vector control services	110
3. Kinds of equipment	110
4. Selection of equipment for environmental management works: the guiding principles	111

1. Introduction

Environmental management works must make use of proper equipment if they are to have a significant impact in any vector control programme. While manual operations and the use of hand tools may continue in limited operations or in remote areas, the aim should be to extend the use of powered equipment on account of the better quality of the work performed, the greater output and other economic advantages.

Several types and sizes of powered equipment for excavating, loading, hauling, etc. are now available in the market throughout the world. Many are employed in agriculture, public works, etc. by private agencies or government services, and arrangements can often be made to use them for environmental management and vector control purposes, either free of charge or at nominal cost. In that case, the problems of equipment use will be fewer since staff training and equipment operation and maintenance remain the responsibility of the owner agencies. Vector control services purchasing their own equipment should start with simple and inexpensive items and continue with more sophisticated machines. Criteria for the selection of types and size of equipment cannot be generalized and must be specific to each programme. Certain common principles can, however, be put forward for the guidance of vector control services (see section 4 below).

2. Justification for the use of equipment in vector control services

Of the various environmental management measures, environmental modification works can benefit most from the use of equipment. The reluctance of programmes to make use of these measures even though they are locally feasible is due to the assumption that they are costly, and failure to appreciate their impact on the control of vectors and diseases by shortening the time required to carry out any major work of this kind. Modern equipment is the key to accelerated execution and to the lowering of cost per unit of work performed. At today's prices, a light tractor-drawn piece of equipment may cost less than a light field vehicle, and a medium, self-powered backhoe with front loader may cost no more than three vehicles. A single item of such equipment has a work output greater than tens and hundreds of labourers and, in addition, does not create the costly and complex organizational, supervisory and logistic problems inherent in the use of a large labour force. The choice of proper equipment, however, is an important factor in optimizing benefits and should be given careful consideration.

3. Kinds of equipment

Many ditches now in use for irrigation and drainage were cut, and used to be maintained, by hand or animal-powered implements and tools. Nowadays, animal power is little used except

for cutting very small open ditches and operating a few scoop-type and fork-type cleaning implements. Since the advent of the internal combustion engine and the development of the farm tractor, cutting and cleaning operations have largely been mechanized, although in many areas in developing countries, and outside agricultural schemes, the farmers still dig their ditches using hand tools.

The work involved in ditch cutting and cleaning is mainly that of excavating soil and shaping a channel and its banks, the removal and disposal of deposited silt and soil, cutting growing weeds, and disposing of them. The major works that can be carried out by mechanized equipment include excavation, scraping, dozing, grading, hauling and compacting. Some of the machines used for this work are listed in Table IIIH-1. They may be drawn by tractors, mounted on tractors, or self-powered. They may be mounted on wheels or on tracks. It is not possible to classify them under the heads of cutting machines, cleaning machines, hauling machines, etc., since they may do several of these jobs. They vary in size and power requirements from light implements up to large heavy machines needing powerful engines. Between these two extremes, there is a large and growing range of medium equipment designed for use with all types of farm tractors and engines. It is not possible in a limited space to describe all the machines that are now in production. In Annex 5 they are discussed under broad types and categories rather than as individual and particular makes of machines.

4. Selection of equipment for environmental management works: the guiding principles

The key to the selection of the type and make of equipment for use in environmental management works should be uniformity and conformity with that existing in the operational area, thus facilitating operation and maintenance. In rural areas, manual and animal-drawn equipment should be selected as a general rule. Where mechanized agriculture exists, equipment designed for use with the existing types of farm tractors and engines may be selected. In cases where vector control services possess adequate funds and qualified staff to carry out medium-size environmental management works, they should also use multipurpose equipment such as backhoes with loaders mounted on wheeled tractors. Specific types of equipment should be bought only if this is fully justified by local needs.

The following considerations should be borne in mind when selecting equipment for environmental management by vector control services:

- (a) Whether an engineer or a public health inspector experienced in environmental management works is available and is heading a unit in the service responsible for these activities.
- (b) Whether funds are available.
- (c) What is the extent and nature of work to be carried out in the next 5 to 10 years.
- (d) What is the texture and composition of earth material to be excavated, hauled away and disposed of.
- (e) What is the haul distance.
- (f) Whether wheeled or tracked equipment is to be selected will depend on the topography of the land. Tracked equipment can negotiate slopes up to 100% (45°). Wheeled machines have serious traction difficulties on wet ground and if slopes are more than 15% (9°).
- (g) What are the cost of the machine and that of its operation and maintenance.
- (h) What skill is required for its operation and maintenance.
- (i) Should equipment be multipurpose, capable of performing several different environmental management and agricultural operations.

Table IIIH-1. Construction equipment*

Type	Size (horsepower, volume)	Class (light-medium- heavy)	Use in excavating and filling
1. Mouldboard plough	animal-drawn	light	Cutting and maintaining small ditches
2. Small ditching plough	animal-drawn	light	Cutting and maintaining small ditches
3. Large furrow- type ditcher with wings	tractor-drawn	light-medium	Cutting small ditches
4. Motor grader	125-250 hp	light-medium- heavy	Cutting ditches, mixing and grading earth materials, smoothing earth surfaces
5. Angle blade dozer D4-D10	62-700 hp, blade width 3.1-6.0 m	light-medium- heavy	Cutting ditches, bulldozing earth, building embankments, rough filling and digging over short distances
6. Home-made drag ditcher	Pulled by animals or farm tractor	light	Cutting and cleaning small ditches
7. V-type ditcher	Attached to farm tractor	light	Cutting and maintaining small ditches
8. Track excavator (backhoe)	85-325 hp bucket 0.57-2.5 m ³ , digging depth 3.86-5.45 m	medium-heavy	Digging medium-to-large canals, open drains, filling medium- to-large trenches, loading trucks
9. Wheel excavator (backhoe) -loader	47.5-96.7 hp, backhoe digging depth 3.81-589 m, loader 1134-2631 kg	light-medium	Digging small-to-medium trenches, canals, open drains, ditches. Filling small-to-medium trenches. Loading trucks, moving earth short distances. A very versatile and practical machine.
10. Rotary ditcher	attached to farm tractors 350-140 hp	light-medium	Cutting and maintaining small- to-medium ditches

* See also Annex 5 where a number of these implements are described with illustrations.

11. Wheel front-end loader	100-690 hp, 1.34-9.6 m ³ , breakout force 8700-66700 kg	medium-heavy	Digging, moving loads short distances, loading trucks
12. Track front-end loader	62-275 hp, 0.8-3.82 m ³	small-medium-heavy	Digging, loading trucks
13. Wheel tractor scraper, with tractor pusher	330-550 hp, 10.7-33.6 m ³	medium-heavy	Scraping and moving earth medium distances, building earth embankments, filling trenches and depressions
14. Elevating wheel tractor scraper	150-450 hp, 8.4-26 m ³	medium-heavy	Scraping and moving earth medium distances, building earth embankments, filling trenches and depressions
15. Tandem-powered (push-pull) wheel tractor scrapers	225-550 hp each, 10.7-33.6 m ³ each	heavy	Scraping and moving earth medium distances, building earth embankments, filling
16. Gradall	100-300 hp, 1.3-5.0 m ³	heavy	Ditching, trenching, excavating, grading, filling shaping; a very versatile machine
17. Front-end shovel	195-325 hp, 1.9-3.8 m ³	medium-heavy	Digging hard soils and rock, loading trucks, moving large quantities of earth
18. Dragline	30-120 hp, 20-100 m ³ /hr	light-medium	Cutting and cleaning large open ditches, cleaning weeds from ditches
19. Bucket-wheel trencher	50-200 hp, up to 200 m ³ /hr	light-medium	Continuously cutting trenches, installing plastic drain tubing
20. Plough trencher	Requires 2-D9 tractors as prime movers	medium	For installing plastic drain tubing continuously without digging a trench
21. Compactor	170-315 hp, operating wt. 18170-31560 kg	medium-heavy	Compacting earth embankments, dozing and filling
22. Off-highway truck	450-870 hp, 17.4-46.4 m ³	heavy	Hauling earth materials over long distances, carrying large rocks
23. Special application tractor	68-125 hp	small-medium	Pulling special equipment
24. Wheel tractor	170-315 hp	medium-heavy	Dozing, grading, faster than tractor dozer

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CHAPTER IV

ENVIRONMENTAL MANIPULATION

CONTENTS

	<u>Page</u>
1. Strategies applied to man-made lakes	119
1.1 Description of various impoundments and their relative importance for mosquito production	119
1.1.1 Navigation canals	119
1.1.2 Public water-supply reservoirs	120
1.1.3 Hydroelectric projects	120
1.1.4 Flood control reservoirs	120
1.1.5 Irrigation reservoirs	122
1.1.6 Fish ponds	122
1.1.7 Waste water lagoons	122
1.1.8 Multipurpose dams and reservoirs	123
1.2 Preimpoundment reservoir preparation for water level management . .	123
1.3 Postimpoundment reservoir operations	124
1.3.1 Water level management schedules	124
1.3.1.1 The four phases schedule	124
1.3.1.2 Comments on general applicability to various reservoirs	126
1.3.2 Shoreline maintenance	128
1.3.2.1 Marginal drainage	128
1.3.2.2 Drift removal	128
1.3.2.3 Control of plant growth	128
2. Strategies applied to irrigation systems	128
2.1 Paradox of mosquito problems in arid lands	128
2.2 Elements of water control	131
2.2.1 Irrigation by pumping	131
2.2.2 Groundwater recharge	131
2.2.3 Preparing land for efficient irrigation	131
3. Strategies applied to wet rice cultivation	132
3.1 Monsoon rain or provident irrigation	132
3.2 Labour-intensive or traditional Asian cultivation	132
3.3 Malaria vector production in traditional cultivation	132

	<u>Page</u>
3.4 Energy-intensive or non-traditional cultivation	132
3.5 Malaria vector production in energy-intensive cultivation	134
3.6 Intermittent irrigation and drainage	134
3.7 Other methods of control	135
4. Strategies applied to the control of vegetation in mosquito breeding habitats	135
4.1 Relationship of plants to mosquito breeding	135
4.1.1 The "intersection value" concept	136
4.1.2 Specific plant-mosquito relationships	136
4.1.3 Plants which allegedly inhibit mosquito breeding	137
4.2 Water manipulated as herbicide	138
4.2.1 Required scientific information	138
4.2.2 Seed germination	139
4.2.3 Vegetative methods of reproduction	139
4.3 Practical application	139
4.3.1 Shading by tree planting	139
4.3.2 Artificial flooding	140
4.3.3 Cutting and flooding	140
4.3.4 Recurrent cutting	140
4.3.5 Special mechanical methods	141
4.3.6 Dewatering of aquatic species	141
5. Stream flushing	141
5.1 Antimosquito action	141
5.2 Dry streambed breeders	142
5.3 Rational design of flushing	142
5.3.1 Inflow at peak breeding	142
5.3.2 Automatic versus manual flushing	143
5.3.3 Downstream distance of control	144
5.3.4 Automatic self-priming siphons	144
5.3.5 Design procedure and example	147
6. Coastal flooding and impounding	147
6.1 Open marsh water management	147
6.2 Artificial inundation	149

7. Chemical and physical alteration	149
7.1 Desalination	149
7.2 Salination	150
7.3 Anaerobic decomposition	150
7.4 Physical measures	151
Further reading list	152

1. Strategies applied to man-made lakes

A recent review of dam construction throughout the world revealed that 14 vast man-made lakes, exceeding 14.8 billion m³ capacity, have been created in tropical countries, many of them in endemic areas of malaria or schistosomiasis.

These and other projects have stimulated awareness of their environmental consequences and possible adverse effects on ecology and public health. In the economic planning of developing nations, the possibility of harnessing renewable water resources for generating electrical energy, irrigating cultivable land, managing floods, and transporting products and raw materials has great appeal. The planning and management of such projects, however, are most complex and should cover all areas of environmental impact, including public health, so that on balance the benefit to man is undeniable.

Early in the century, the association of epidemic malaria with man-made lakes in the southeastern United States led the U.S. Public Health Service and other agencies to develop strategies for the control of the malaria vector Anopheles quadrimaculatus in impounded waters.

The regional development concept of river valley authorities, often international in scope, with its multiuse objectives and far-reaching legal and social implications, is so wide-ranging that only governments can take responsibility for these undertakings. They cannot be left to private management or ownership. It is thus the duty of health authorities to incorporate principles and guidelines in the early stages of such water resource development projects, whatever their purpose.

Impoundments present no malaria hazard where a lacustrine or "pond-breeding" mosquito vector is not present in the region. It is not likely that the An. gambiae fresh water complex, the dangerous malaria vector in Africa, could find suitable breeding places on the margins of man-made lakes, except for the puddles that may remain in the drawdown zone despite marginal drainage precautions. Although only a few of the important vectors of malaria can be considered as lake-breeding, when a stream is impounded to form an extensive lake-breeding habitat, a minor anopheline vector may, however, become dangerous by its sheer numbers.

1.1 Description of various impoundments and their relative importance for mosquito production

1.1.1 Navigation canals

The dams and spillways of navigation canals are designed to maintain a constant pool elevation in the canal and to replenish the water consumed for lockage. Canals are excavated with a cross-section side slope which resists erosion by waves created by the passage of boats.

The use of stone or concrete lining is common; where natural earth is used, a flat slope up to 10:1 is adopted. The water storage areas may be extensive, as in the Gatun Lake on the Panama canal, or small, as in the case of lateral canals used to avoid shoals along navigable rivers. The Gatun Lake has a marsh potential^a of 15 m^{-1} whereas the Colbert shoals canal has a potential of only 1 m^{-1} . The unprepared Gatun Lake has been associated with endemic malaria transmitted by *Anopheles albimanus* which breeds in the floating mats of aquatic plants among the drift, floatage and dead timber. Thus, while navigation canals may be of minor importance because of the frequent disturbance produced by the passage of boats, the impoundments connected with these canals can be a major breeding place for mosquitos.

1.1.2 Public water-supply reservoirs

Impounding reservoirs are built on upland streams for the purpose of storing freshet flows for use during those times when the natural flow of the stream is insufficient to maintain a safe yield. The size of the catchment area and the study of rainfall-runoff cycles will provide data to determine the storage needed to compensate for daily fluctuation within a single year and the annual storage to carry over the surplus of wet years for use during dry years. The water level variations in the reservoir can be quite wide, up to 3 m or more during a normal year and considerably greater during drought. Since the water quality is of prime importance for drinking water sources, the preimpoundment reservoir preparation is mandatory (see section 1.2 below). In the tropics, algae and aquatic blooms are most troublesome, and may encourage mosquito production.

1.1.3 Hydroelectric projects

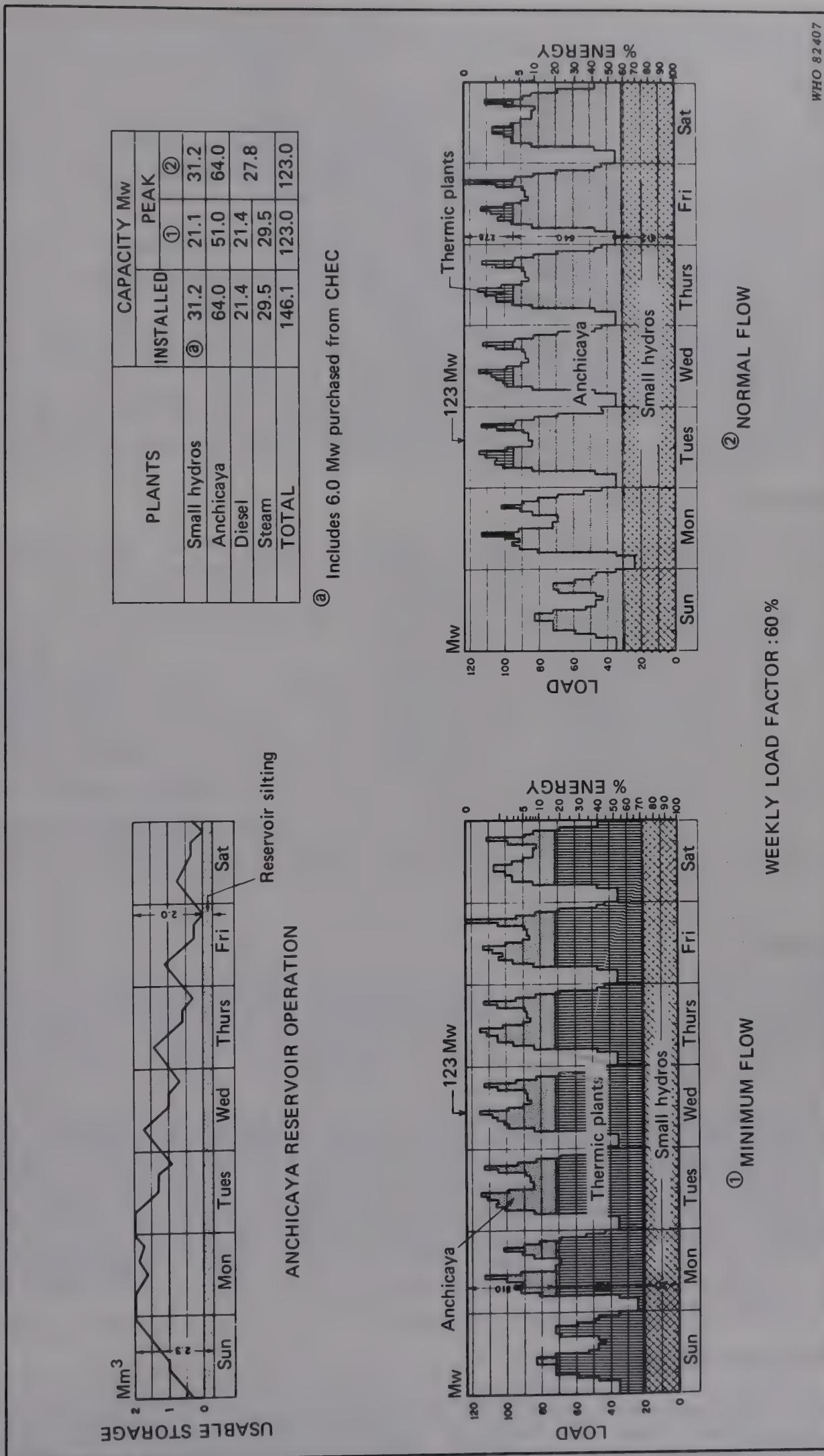
The capacity of the power-generating equipment and the load demand are closely related to the quantity of water available and the storage provided. The height of the dam is usually partly dictated by these requirements. It is usual for a hydroelectric power plant to serve a large electric system in combination with auxiliary (steam or diesel) power stations as dictated by the daily and seasonal energy load curve. In general, the hydro plant is used when the load increases towards the peak demand so as to use as much of the plant capacity as stream flow and storage will permit. In periods of low flow, the plant may operate only during peak load periods; during high flows, it may take the base load. Fig. IV-1 gives an example of a service system showing this principle of shifting the base load from hydro to steam during the period of low stream flow. It should be noted that hydro operation during normal flow will deplete the available reservoir storage throughout the week in the expectation of its being refilled during the weekend offload period. This results in a cycling of reservoir levels quite consistent with good practice for anopheline mosquito control.

1.1.4 Flood control reservoirs

A "flood" refers to an overflow of a river or other body of water that causes loss of life and serious damage to structures in the flood plains. Farm, forest, and pasture land exposed to occasional floods can be guarded by protective embankments (levees) on either side of the river. It is as a protection against exceptional floods that large storage reservoirs are required. The cost of flood protection works (such as dams, channels and levees) may, however, be disproportionate to the probable flood damage, especially if the siting of towns in the "flood plain" is discouraged. The single-purpose flood storage reservoir is most effective when it is completely or nearly empty at the time the flood occurs because a maximum reduction of flooding downstream is then possible.

^a Marsh potential is defined and interpreted in section 2, subchapter IIIA.

Fig. IV-1. The relationship of small and large hydro plants and standby power plants on the base load of electric power systems during normal and minimum stream flow conditions showing the compatibility with weekly water level fluctuation.



A flood during the mosquito season can be expected to result in almost uncontrollable mosquito breeding in flood storage pools which are overloaded and packed with drift and floating mats. It will take two weeks or more for the habitat to "ripen" and provide maximum larval densities, but high adult mosquito populations can be reached even sooner. The rapid lowering of the storage pool after the flood crest has passed is accompanied by a dramatic abatement of mosquito breeding as eggs and larvae are stranded with the drift and floatage on the steep reservoir slopes. Reservoir preparation will greatly assist in controlling mosquito production, especially by removal of timber and by marginal drainage.

In planning flood control, the extent and reliability of hydrographic data are most important, since inadequate data may result in over-designed and unnecessary storage or downstream safety measures. Care is necessary in deciding the level below which the reservoir should be cleared of trees. If the cleared area is not flooded at least once in 3 years, the trees will grow up again. If the tree-clearing level is too low, large areas of timber may be flooded so frequently that the trees die and have to be removed. Most trees withstand floods of short duration during the growing season and extended floods during the dormant period. In flood storage pools, often sited in steep, head waters of river basins, the timber species cannot survive if flooded more than 5-10% of the time during the growing season.

1.1.5 Irrigation reservoirs

Surface reservoirs are built to store irrigation water for use when the natural flow of a stream is not sufficient to meet demands. Usually the winter and spring runoff can be impounded until needed for crop growth. Evaporation and seepage losses are a serious problem of storage reservoirs in arid areas, as is sediment accumulation which may limit the useful life of the structure. The popular tendency is to associate water storage for irrigation with the enormous government-built dams for reclamation of desert areas. These projects are generally of the multiuse type, less likely to contribute to malaria vector problems than the thousands of small earth dams and reservoirs in farms throughout the world which are commonly referred to as "tanks" or "bunds". Irrigation reservoir operation is essentially a cycle of seasonal filling, storing and gradual release (as needed) throughout the growing season. With proper reservoir preparation, only a modest mosquito vector production problem would be expected. The worst vector breeding conditions appear after off-seasonal rains which flood the pools and encourage vegetation on margins of the partially emptied reservoir. Correct water level progression measures will be resumed with the normal release of water for irrigation.

1.1.6 Fish ponds

In some parts of the tropics and subtropics, fish culture ponds have constituted a breeding place for the local malaria vector. The classical example is the breeding of the vector *Anopheles sundaicus* in the saltwater fish ponds of north Java. Today the need to contribute to the food economy, especially in countries deficient in protein, has resulted in a regain of interest in the pond cultivation of edible fish. Usually low-lying lands, subject to flooding during the rainy season, are chosen for fish ponds. An embankment is raised beside the river and tributary streams, and encloses an area which is partitioned into large cells by secondary bunds or dikes constructed with the material excavated from the pond area. During the flood time, millions of young fish are allowed to enter the enclosed ponds. A similar pond area may be constructed in large tidal flats for the cultivation of saltwater fish and prawns. Attention is now being paid to the role of floating aquatics such as *Pistia* and water hyacinth. The emergent plants offer protection to larvae, make the control of anopheline mosquitos difficult, and may interfere with the growth of desirable organisms and the oxygen balance of the pond.

1.1.7 Waste water lagoons

One biological method of waste water treatment is the use of artificial lagoons or stabilization basins, often referred to as oxidation ponds. The pond area and depth required depend upon the strength of waste and the processes involved, either anaerobic, facultative

or aerobic. Anaerobic lagoons are intended for very strong wastes; they are foul-smelling and covered with a thick scum. No anopheline species would select this habitat; however some filth-loving culicines and flies would.

The facultative lagoon has been designed to allow for satisfactory levels of oxygen production by naturally generated algal populations. In this type of lagoon, anaerobic decomposition takes place in the lower portion while algae growing near the surface provide oxygen for aerobic processes. In between is a range of dissolved oxygen from zero to super-saturated on sunny days. The major design requirement is that the lagoon should not become completely anaerobic during the night or on cloudy days. The potential for mosquito production of a facultative lagoon is high, unless the shoreline is steep, preferably with stone rip-rap, and the pond deep enough to prevent the growth of emergent aquatic vegetation. Provision should be made for partial emptying of the pond for shoreline maintenance. The high rate aerobic pond is really an aerated lagoon, and is similar to an activated sludge tank without recycling. It has limited application in developing countries. The design is on a somewhat firmer basis than that of the facultative lagoon. Its operation depends partly on incident solar radiation and loading rate but also on experience and judgement. Ponds in series, as opposed to a single basin, can control short circuiting but increase the area of the mosquito breeding edges. Below are given some design parameters recommended for general use.

Typical oxidation pond design

	<u>Anaerobic</u>	<u>Facultative</u>
Depth (m)	2.5-3.5	1-1.5
Detention (days)	30-50	7-30
BOD*(g/m ² /day)	33-56	2.2-5.6
BOD removal (%)	50-70	70-85
Algae conc. (mg/l)	None	10-50

(*biochemical oxygen demand)

1.1.8 Multipurpose dams and reservoirs

The building of a system of multipurpose dams and reservoirs will have both direct and indirect implications for the health of the people of the region. For example, vast irrigation projects for wet rice crops and cane cultivation have too often had adverse effects on the health and welfare of the people who, it was hoped, would benefit socially and economically from the project. Therefore any regional multiuse water resources enterprise must allow for possible conflicts of interest, and ensure that the result is constructive or at least not damaging. Appropriate measures should be incorporated in the design, construction and operation of such systems for the control of mosquitos and the prevention of other health hazards (see Chapter III).

The concept of integrated regional development must include a strong public health component from the start of the planning phase. Too often, measures for disease prevention are not incorporated in the enterprise until postconstruction difficulties arise, and corrective measures are more expensive to apply and less likely to be successful. Further, construction safety and medical service organizations do not necessarily include preventive medicine measures, and cannot be relied on for the protection of the health of the population affected by the enterprise.

1.2 Preimpoundment reservoir preparation for water level management

Certain basic environmental management measures, if properly carried out, are generally quite effective in controlling mosquito production on impounded water. They comprise the preparation of the reservoir prior to impoundment, and a programme of water level management designed to strand drift and floatage, minimize the invasion and growth of marginal plants which provide the habitat for anopheline propagation, and suppress aquatic plant colonization.

The purpose of preimpoundment preparation is to clear and otherwise prepare the basin prior to filling so that in principle a clean water surface will result at all elevations between high and low level. This subject is discussed in detail in subchapter IIIA above. The technique and objectives of water level management for mosquito control are explained in section 1.3.1 below.

1.3 Postimpoundment reservoir operations

1.3.1 Water level management schedules

The major strategy of malaria mosquito control following impoundment is water level management. Almost every reservoir has some predictable pattern or "rule curve" of water level changes throughout a normal water year. The water year does not coincide with the calendar year but rather with the cycle of rains and runoff which is particular to each catchment area and may be quite different from that at the reservoir site itself which, in some cases, may be a perpetual desert (Nasser Lake, Egypt). The maximum opportunity to make use of water level changes for mosquito control is found within a multiuse system of reservoirs where water control is highly developed. Through biological investigation and field appraisal, an improved and integrated system of "rule curves" has been developed for the reservoirs of the Tennessee Valley Authority (TVA) system in USA which set the bases for control of malaria vectors and of the marginal vegetation which supports their development. Today, water level management alone controls anopheline mosquito production on most of the 30 major TVA reservoirs. The elements of the schedule are given in Fig. IV-2.

1.3.1.1 The four phases schedule

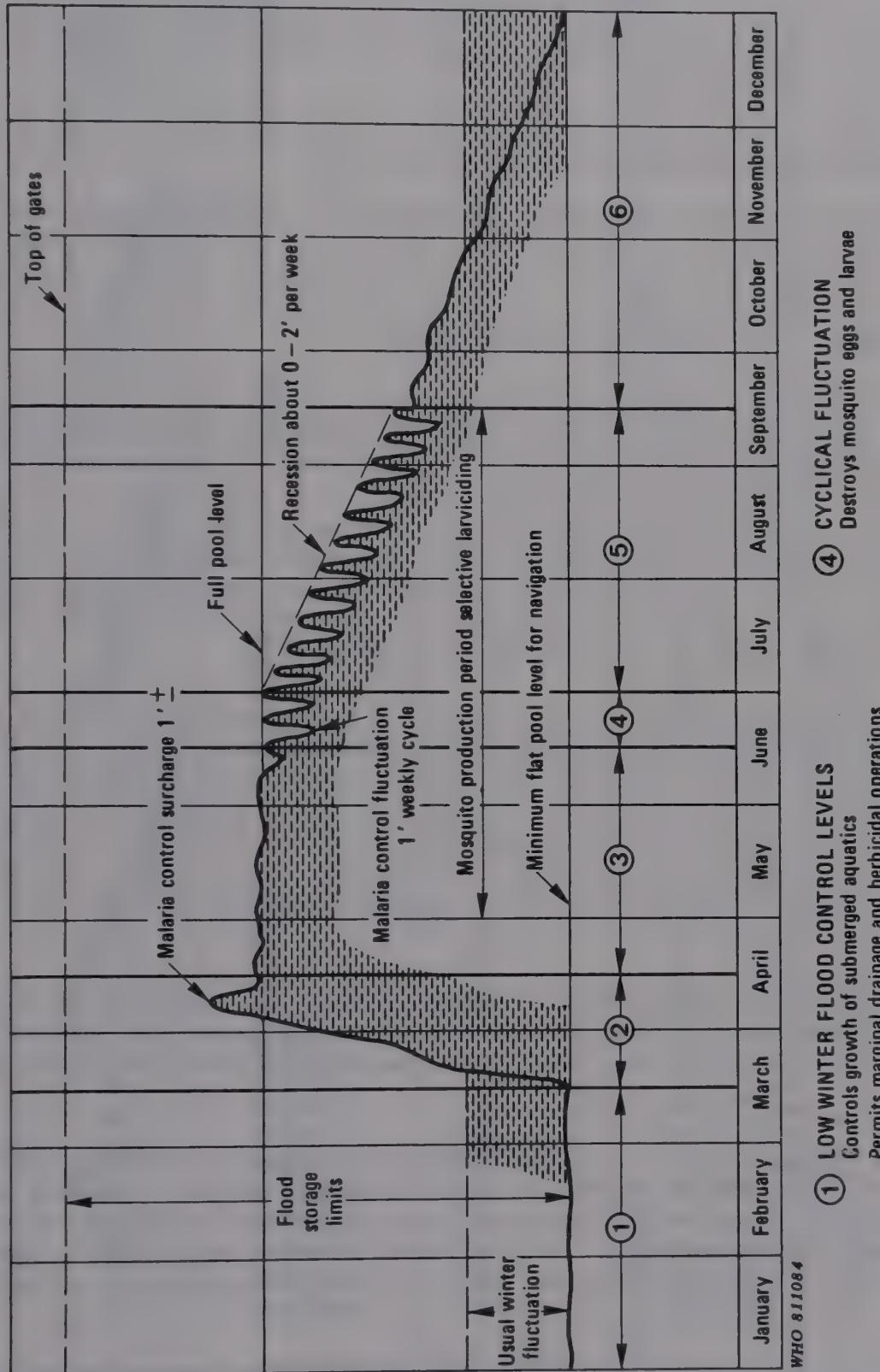
The first phase involves filling the reservoir to provide a surcharge (early spring in temperate zones) of 30 cm or more above normal full pool, followed by a rapid draw to full pool level. Depending upon the stream flow, the time for filling and surcharge will be variable. For mosquito control purposes, the surcharge serves to strand accumulated drift and floatage and is required for only a few days.

The second phase involves the maintenance of a relatively constant full pool level at the clearing line until the beginning of anopheline mosquito production. The constant pool level limits invasion of semiaquatic marginal vegetation into the fluctuation zone, thus providing a clear shoreline when the water is drawn down later in the season.

The third phase consists of weekly fluctuations starting when larval populations reach significant numbers. This calls for the lowering of the pool about 0.3 m and refilling during the week. In a hydroelectric project, the cycle is not too difficult to achieve since the load factor is less over the weekends. In a system of reservoirs, the load may easily be shifted to permit either drawdown or reflooding as required. The purpose of the fluctuation is to draw down the water level and expose the marginal band of vegetation once a week, thus eliminating the larval habitat. The antimosquito action is threefold: it creates unfavourable conditions for oviposition, it interrupts the production of food organisms for larvae, and it exposes larvae to the predation of their natural enemies. Furthermore, some larvae and eggs are stranded in the dewatered area where they die by desiccation or are eaten by ants and other predators before the water is raised. The reflooding serves to delay the growth and invasion of marginal vegetation. Thus, while the first two phases of the management programme are directed at the mosquito habitat, the third phase (cyclical fluctuation) is directed against both the habitat and the mosquito. The amplitude of the weekly cycle need not exceed 0.3 m so long as water is largely withdrawn from the marginal vegetation at the low point of the cycle. Neither is a full 0.3 m cycle required if the vegetation has not invaded far enough into the pool to justify that amplitude.

The fourth phase of the ideal water level management schedule consists in combining seasonal recession and cyclical fluctuation. After a few weeks of the third phase (water level fluctuation), field observations and measurements of mosquito density levels will show that a clean margin is no longer provided at the low point of the cycle. The pattern of level

MALARIA CONTROL FEATURES OF WATER LEVEL MANAGEMENT ON TVA MAIN RIVER RESERVOIRS



① LOW WINTER FLOOD CONTROL LEVELS

Controls growth of submerged aquatics
Permits marginal drainage and herbicidal operations

② EARLY SPRING FILLING

Retards plant growth
SURCHARGE
Strands drift above full pool level

③ CONSTANT POOL LEVEL

Provides long-range plant growth control

④ CYCLICAL FLUCTUATION

Destroys mosquito eggs and larvae

⑤ FLUCTUATION AND RECESSION

Destroys eggs and larvae

Reduces breeding area

Provides clean shoreline

⑥ RECESSION TO WINTER LEVELS

Permits fall shoreline maintenance and
improvement operations

Fig. IV-2. Desirable phases of water level management for the control of pond-breeding anophelines on multiuse impoundments.

fluctuation must then be changed. The water level is lowered 0.3 m as before, but is subsequently raised only 0.27 m on reflooding. This is referred to as "seasonal recession" since the period coincides with the decrease in stream flow and the increase in the use of water for downstream navigation, flow augmentation, and irrigation. The controlled recession serves to ensure that the low point of the weekly cycle will draw the water sufficiently far below the advancing vegetation to control mosquito production. If stream flow and withdrawal rates permit, the recession rate per week should be kept to a minimum since the sharper the recession the broader will be the band of marginal plants requiring some shoreline maintenance before the flood storage phase begins anew.

1.3.1.2 Comments on general applicability to various reservoirs

The four phases schedule represents the ideal management for temperate zone climates where advantage can be taken of the winter period. It is based on the assumption that flood stages will occur normally in the late winter or early spring period, and that the system of discharge regulation from both storage and main stream reservoirs will be sufficiently flexible to allow the proposed rule curves to be maintained.

Even in the temperate zone very large reservoirs cannot respond to weekly cyclical fluctuation requirements, and for mosquito control they must rely instead on regulated seasonal recession. The storage reservoir also cannot follow the four phases because its situation at the head of a tributary stream makes it subject to an annual rhythm of fill and draw. Filling takes place during the winter and early spring and, after a short storage period, water is released to maintain downstream flow as the summer progresses. Properly-prepared storage reservoirs do not present serious malaria mosquito problems when they are built in steep mountainous terrain with a cool climate, and when they have wide seasonal recessions which draw down well ahead of invading marginal vegetation.

Some reservoirs are neither provided with flood storage nor operated to give wide seasonal recessions. These are mostly operated at nearly constant pool levels, as is the case in some hydroelectric projects. Where inflow is not scarce, cyclical fluctuation alone may offer the best mosquito control when coordinated with maximum and minimum weekly power factors. Fig. IV-3 illustrates the mosquito control efficiency of several water level management schedules for a hydropower reservoir with no flood surcharge and only 0.6 m recession. It has been observed that when the water level in reservoirs remains constant, mosquito control fails despite lavish larvicultural operations.

A difficult question is how to adapt water level management, as practised in the USA, to tropical zones where there is no winter interruption in vegetation growth and mosquito propagation. There is reason to believe, however, that water management principles can be applied fairly well everywhere.

The storage surcharge phase is the most undesirable feature in the tropics. The problem resides in the rate of refilling and the promptness of drawdown to ensure stranding of floatage. If the water level rises slowly over several months in margins covered with vegetation, emergency larvicides may have to be employed. With a rapidly rising water level, the danger may be insignificant because of the latency period required for the maturation of the new larval habitat.

Most tropical reservoirs are located on large rivers fed by high torrential rainfall, often with 80% of the annual flow in 2 to 3 months of the year. Reservoirs usually have large storage volumes to carry over the dry years, and turnover rates varying from once in 5 years (Volta) to once in 9 years (Kariba). At the beginning of the flood period, the reservoir is likely to be quite low and much of the flood flow will be over the barren shoreline. When the progressing water level reaches the vegetation band, usually the weather will be clear with cool nights. This may retard mosquito development from egg to adult to perhaps 2-3 weeks, depending somewhat on altitude. Soon thereafter, the water level will reach its peak and slowly, then rapidly, start its annual seasonal recession. The dewatered shoreline will be

MOSSQUITO CONTROL AND WATER LEVEL FLUCTUATION - WILSON RESERVOIR

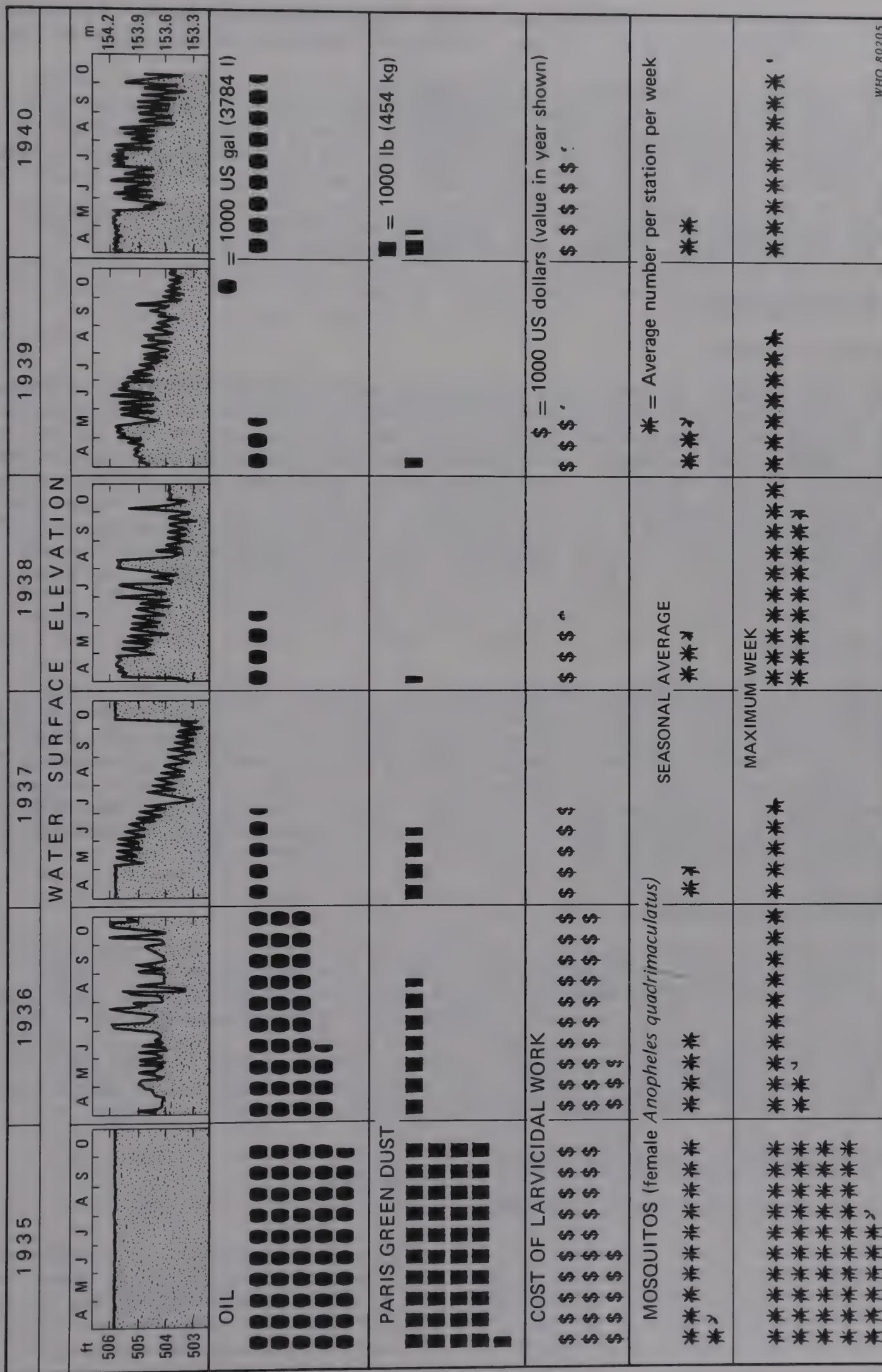


Fig. IV-3. Comparison of the mosquito control effectiveness of different water level management schedules on a hydroelectric impoundment with a limited fluctuation range.

progressively exposed to hot, dry weather and highest evapotranspiration rates. With good water level fluctuation and marginal drainage, maintenance mosquito problems should be minimal.

The greatest threat to the success of the strategy of water level management is the colonization of floating mat types of aquatic plants. A low effectiveness of water level management techniques may be expected in areas colonized by these plants. Impounding reservoirs may have a high potential for such colonization and therefore high mosquito control costs. There are many floating mat species of plants in tropical and subtropical areas. They include the water hyacinth (*Eichhornia*), water chestnut (*Trapa*), water primrose (*Jussiaea*), alligator weed (*Alternanthera*), water lettuce (*Pistia*), water milfoil (*Myriophyllum*) and *Salvinia*. The control of aquatic plants is discussed in section 4.3.5.

1.3.2 Shoreline maintenance

1.3.2.1 Marginal drainage

An effective system of reservoir marginal drainage must be maintained if full advantage is to be taken of the strategy of water level fluctuations for mosquito control in impounded water. The drainage works constructed during the preimpoundment period are like the "tip of the iceberg" compared with the number of undrained depressions discovered after impoundment. If left undrained, isolated pools will continue to produce mosquitos. Pest mosquito problems also occur in shallow depressions in the zone between high and low pool levels. Since the habit of floodwater *Aedes* sp. is to lay eggs on the dry soil of the depression, enormous broods emerge later on when the area is reflooded. The annual maintenance should include a survey to identify new pools to be drained, as well as the regrading of old ditches where necessary.

1.3.2.2 Drift removal

If storage for a flood surcharge is available, the problem of annual drift removal is minor and concentrated in the heads of bights and indentations where a cleared space should be provided for stranding the material. Such accumulations are usually piled and burned. After a few years, the drift problem should abate unless erosion clearing (see subchapter IIIA, section 3.2) was underestimated or not considered at all. If storage for flood surcharge was not provided for in the project design, no stranding will take place and drift removal will have to be done when the reservoir is low; this may require expensive physical removal of mats of floating material in the water.

1.3.2.3 Control of plant growth

The band of invading vegetation which can be limited by controlled water recession rates is largely destroyed during the reflooding phase of water level management. In temperate zones, frost kills most of the annuals before the water is raised. The tolerant woody plants may present problems in the broad, flat and protected areas of the fluctuation zone. They collect and contribute to floatage, retard wind and wave action, and diminish the antilarval effect of water level management. Such woody plants should therefore be controlled by annual hand cutting or mechanical sawing. An alternative method in some areas is to thin out such plants in order to grow a stand of trees to provide shade (see section 4.3 below).

2. Strategies applied to irrigation schemes

2.1 Paradox of mosquito problems in arid lands

Irrigation is needed only to supply plants with water for consumptive use or evapotranspiration. Evapotranspiration is the sum of two terms: (a) transpiration, or the water used by the plant for growth processes, and (b) evaporation or the water evaporating from the soil, the water surface or the surface of leaves. It is hard to generalize on water for consumptive use because of the large number of variables involved, but the quantity required must be

estimated for both "wet" and "dry" crops so that the engineering design is based on valid irrigation water needs.

In many countries, irrigation is an art as old as civilization, but there is evidence of a reluctance to profit from past mistakes, which are many. On arid and semi-arid lands the manipulation of irrigation water is a modern science. The engineer and agriculturist must maintain suitable conditions of soil moisture for maximum crop yields by providing water to the field in the amounts required at the proper time and for the necessary duration.

Generally, the arid land soils already possess most nutrient elements but, due to scanty rainfall, they are apt to be saline. Irrigation water quality, as expressed by the total dissolved solids, is an important factor in the accumulation of excessive salts in the soil. The removal of salts through soil leaching is obtained by the application of excess irrigation water. Inadequate waste water drainage is a contributing factor that increases the leaching requirement.

Failure to recognize these factors has spoilt usable land by "waterlogging", injured public health and resulted in the economic collapse of ancient as well as recent systems on arid lands. Land conservation and mosquito breeding problems in these systems can be largely prevented by sound water use and management techniques. In some malarious regions, well organized large-scale irrigation systems are rare, and problems arise mainly in small systems whose management is left to the farmers themselves. In Indonesia, for example, only 20% of irrigated crops are produced in large engineering projects and 80% by simple diversions and rainfall capture. Even public projects in some countries will reveal lapses such as: (a) failure to study preirrigation factors needed for design; (b) failure to provide proper conveyance and distribution facilities beyond public canals; (c) failure to prepare fields for the application of irrigation; (d) general inadequacy of drainage; and (e) lack of farmers' education and guidance on irrigation practice, water quantity and watering schedules.

The main cause of waterlogging and consequent mosquito breeding is the excess use of free and plentiful water. Wild flooding is a crude means of applying water to the land without dikes or furrows to guide the flow and ensure its uniform spread. It is a most inefficient method and when the field is poorly prepared, it leaves permanent pools where mosquitos breed.

Where water is scarce and costly to convey, excessive losses must be avoided. These include losses during conveyance (from source to farm) and application to the root zone, and losses due to inefficient consumption. The annual overall efficiency, i.e., the proportion of the water diverted that is actually used by the crop, is often poor as shown in Fig. IV-4 for a typically semiarid region. Long continuous runs of irrigation, i.e., long distance from head to tail of field, are as undesirable as underirrigation and promote waterlogging.

A second cause of waterlogging and mosquito breeding is the seepage from canals, laterals and ditches. An effective way to prevent or reduce seepage losses is canal lining, which is dealt with in detail in subchapter IIIB, section 6.

A third cause of waterlogging and mosquito breeding on irrigated land is the natural stratification of the soils in layers of pervious and impervious material. The application of excess irrigation water cannot percolate downward and results in poorly drained areas.

A fourth cause is the uncontrolled water flow from wells under artesian pressure. Many wells are never valved off. In some instances, a poorly sealed casing will leak artesian water, forming seep areas that are difficult to correct.

DISPOSITION OF WATER DIVERTED FOR
IRRIGATION IN A SEMI-ARID REGION

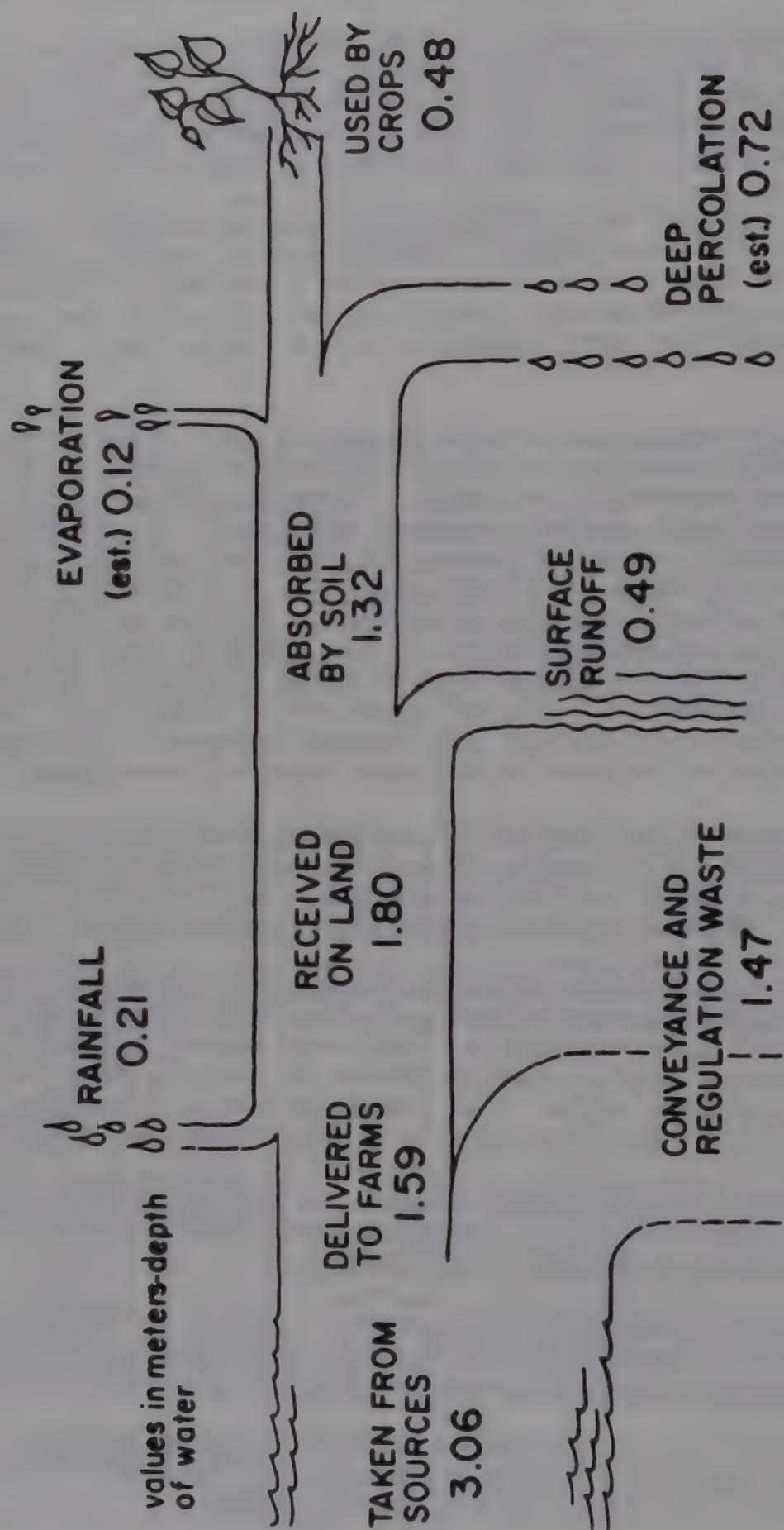


Fig. IV-4. Estimated utilization of water during one irrigation season, including conveyance losses (due to seepage and spillways) and farm-delivery losses resulting from evaporation, percolation and surface runoff.

The history of irrigation shows that while some failures (waterlogging) may be due to economic conditions or human behaviour and a few to lack of adequate engineering, most failures have their origins in unfavourable conditions of water, soil and drainage. No method can solve all the drainage problems; some simply call for improvement and maintenance of the natural drainage, others require the construction of complete drainage systems. Drainage methods are discussed in detail in subchapter IIID.

2.2 Elements of water control

In tropical areas, irrigation is used to augment natural rainfall and ensure the availability of water when needed. This is particularly true of wet crop cultivation where irrigation systems allow more than one harvest per year. In a warm, humid climate, perennial irrigation intensifies the threat of year-round anopheline breeding. For example, in the coastal zone of Guyana the annual rainfall is 2 m, yet a vast system of sea defences and irrigation channels has been developed to increase rice and sugar cane production. Consequently the production of *An. darlingi* went on without interruption all the year round in slow-moving canals and flooded fallow fields. It is not surprising that malaria used to be endemic before countrywide control operations were carried out.

2.2.1 Irrigation by pumping

Under most conditions the initial cost of a gravity system of irrigation will be less than that of a system with wells and pumping plants. Where hydroelectric energy is plentiful and cheap, however, a gravity system may prove to be twice as expensive as a pumping system if all the heavy costs of conveyance and maintenance are considered.

The diversion of irrigation water from multiuse reservoirs (via gravity conveyances of canals, chutes, flumes and tunnels) restricts the utilization of the head or flow for other purposes such as the generation of electric energy. When the irrigation needs are met largely by pumping surface or ground water, much of the extensive conveyance system is eliminated, and the storage water otherwise diverted can be fully utilized to produce hydroelectric power. The amount of water available for irrigation is in no way diminished. Pumping, combined with end of season gravity systems, gives better control with less waste and considerably less vector breeding potential.

2.2.2 Groundwater recharge

Groundwater storage can hold far more water than surface reservoirs, yet it is not fully utilized to hold flood water. Storage in groundwater reservoirs avoids loss by evaporation and entails no mosquito breeding potential. In view of the enormous cost of a single purpose irrigation storage reservoir, the utilization of underground storage is often promising, particularly where it is desirable to lower the groundwater level by pumping. Storage systems are not useful if they are kept full or nearly full. Irrigation by pumping during the dry season will provide the storage space for the wet period recharge. Water for recharging comes from rivers or rivers diverted into canal systems. The water spreading is performed by basins, furrows, flooding or by the use of pits, shafts and wells. Each method has its advantages and disadvantages. In developing countries where multipurpose dams have been built, excess power during off-peak and surplus power periods may be used for water spreading for groundwater recharging.

2.2.3 Preparing land for efficient irrigation

The objective of preparing land to receive water applied by surface flow is to grade the land to a uniform slope in the direction of irrigation and remove the transverse slope as much as possible. Land can be graded to no slope or flat grade for wet crop cultivation but for large fields this presents drainage and mosquito breeding problems. The practice of land filling and grading is discussed in subchapter IIIF.

3. Strategies applied to wet rice cultivation

Grains occupy about half of the world's croplands and rice is probably the most important crop as it is an indispensable food for over half of the world's population. Although 91% of the rice crop is grown in tropical Asia, rice can be cultivated in any warm climate provided that the high consumptive use of 1.65 m of water per growth season can be met.

3.1 Monsoon rain or provident irrigation

No single element plays a more decisive role in the life of tropical Asia than the monsoon rainfall pattern. The seasonal inundation of the flood plains, leaving a rich deposit of mud, coupled with the warm humid climate, creates conditions ideal for the growth of rice. While highly developed irrigation is coming into use in order to double crop production, the almost universal practice is the provident or natural accumulation of water during the rainy season, with harvests restricted to one per year.

3.2 Labour-intensive or traditional Asian cultivation

Most rice paddies are small terraces with level benches and dikes to impound and store water. The fields are ploughed at the beginning of the rainy season and puddled up to a fine consistency for transplanting seedlings. The work is carried out by man and animal power.

About a month before the rainy season, the seedbed is planted. When the young shoots are 20 to 30 cm long, they are pulled and transplanted to the prepared rice paddy. The goal then is to maintain the paddy submerged in 2.5-10 cm of water, but this is difficult to attain when relying only on rainfall. About a week before harvest, the paddy is drained and the field dried.

3.3 Malaria vector production in traditional cultivation

The traditional method of rice cultivation offers possibilities for the intensive breeding of some species of anopheline mosquitos. At first the widely-spaced young plants afford little protection to the eggs and larvae of anopheline mosquitos. As the plants, as well as weeds, grow and fill out, the spacing disappears and a larval habitat is constituted. When the height of the rice stalks reaches 60-75 cm, there is evidence that anopheline mosquitos have difficulty in laying eggs on the water surface and the larval habitat is far from being optimum. This is indicated by the observed reduction in the number of larvae in the paddy during the later stage of rice growth. Following dewatering of the rice field for harvest, the mosquito production terminates. During the period of natural flooding, two or three significant peaks of anopheline production may be observed. Fig. IV-5 presents confirmatory data, obtained from a study carried out in 1950 of malaria associated with rice fields in the Western Pacific. Two crop harvests are made possible by the use of artesian wells to irrigate the paddy prior to the rainy season. Note that the production of an important malaria vector, An. minimus, is not associated with the crop cycle but rather with the beginning and end of the rainy seasons, May and October, when the streams are no longer at flood stages and become clear and cool with the margins covered with vegetation. The more abundant vector An. sinensis breeds in ponded water and rice fields.

3.4 Energy-intensive or non-traditional cultivation

The actual yield of rice in the traditional Asian method of flooding is apt to be lower than that obtained by non-Asian agricultural methods. This is because the former method greatly relies on rain which may be short in some years, and generally does not use fertilizers and pesticides. Sometimes considerable loss is suffered during typhoon winds. The traditional Asian rice yield ranges from 1500 to 2000 kg per hectare, while the energy-intensive methods (making use of irrigation, fertilizers and pesticides) that are now practised in Japan, the Republic of Korea and some other areas are able to produce yields that are the double of this and compare with those obtained outside Asia.

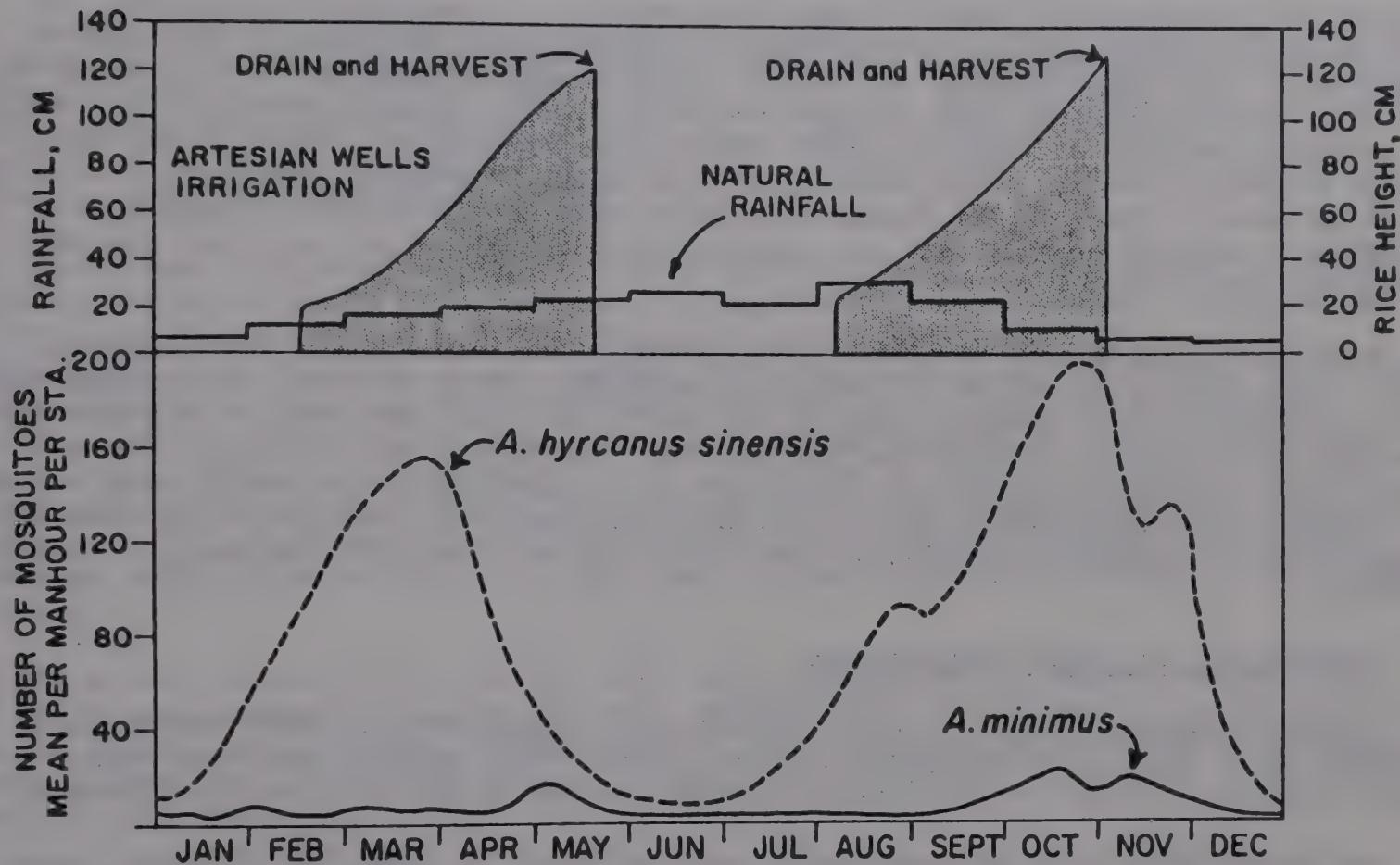


Fig. IV-5. Anopheline mosquito density associated with two-crop wet rice cultivation in the Western Pacific. Dry season crop irrigated with groundwater.

In contrast to the labour intensive methods of rice cultivation in which the seedlings are transplanted by hand to the flooded and prepared field, a high degree of mechanization may be employed. The fields are ploughed, disked and harrowed, and contour levees are formed before the seed is drilled into the dry soil or spread over from the air. After seeding, the rice can grow very much as any other grain, with only light irrigation to keep up soil moisture if the rains fail. It has been experimentally determined that the highest yield of rice is obtained when young rice plants are flooded after 30 days' growth and then kept submerged in water 15-20 cm deep until the rice matures. Then the water is slowly drained so as

not to weaken the straw. After the fields have been two weeks without water, the machines can easily run on them for harvesting. The method of drilling seed has given way to aerial spreading methods.

3.5 Malaria vector production in energy-intensive cultivation

In rice fields where seeding is done by broadcast, mosquito production begins only after the first flood on the 30-day-old rice seedlings. The depth of water on the elongated plants is such that the protective cover for eggs and larvae is at a maximum. Consequently, the first month of flooding results in high mosquito production and densities of more than 20 larvae per m^2 have been reported. As the rice stalks lengthen, they tend to thin out at the water line and the flexuous leafy portions are largely above the water surface. This results in diminished mosquito breeding and limits larval development to open places in the field, such as turnouts, scour holes and levee gates. The number of mosquito broods could be as high as six but usually the first few produce sufficient densities for malaria transmission. According to experience in the USA, one strategic draining applied at the proper time will suffice to control disease transmission.

Agricultural technology is providing new varieties of rice which, in some instances, require fewer days to mature and may permit an extra crop during the year. Where supplemental water is available, more standing water is left on the field and more vectors of public health importance are produced. In addition, the resultant removal of the constraints of water control will provide the farmer with flexibility in his planting and harvesting dates so that all stages of rice growth are present in the area simultaneously. This will complicate vector control (e.g., of mosquitos, snails, or rats) by either environmental management or chemical methods.

3.6 Intermittent irrigation and drainage

A water management scheme has been developed which replaces continuous submergence of ricefields by a series of flooding and draining cycles. This provides excellent vector mosquito control although it is primarily intended for the control of rice plant diseases.

An intermittent irrigation experiment^a was carried out in south Portugal over 4 years, from 1936 to 1939. The experimental area covered a total of 1.53 hectares; this was divided into two plots of approximately equal area, intermittent irrigation being tried in one plot while the other served for comparison purposes. The methods of irrigation, i.e., intermittent versus continuous, were alternated in the two plots yearly. As the local vector, An. atroparvus, takes at least 18 days to complete its development from the egg to the adult stages during the warmest part of the summer under local conditions, a 17-day cycle was adopted in the experiment, i.e., 10 days with water turned on and 7 days with fields drained and water turned off. The rice variety planted was "Chinez".

It was found from the experiment that:

- (a) The rice yield was usually higher with intermittent irrigation.
- (b) A reduction of at least 80% in the number of large larvae was obtained with intermittent irrigation.
- (c) Intermittent irrigation used less water in each parallel test run.
- (d) Intermittent irrigation did not harm the qualities of rice.
- (e) There was less weed and algae growth in fields under intermittent irrigation.

^a Hill, R.B. & Cambournac, F.J.C. Intermittent irrigation in rice cultivation, and its effect on yield, water consumption and Anopheles production. American journal of tropical medicine, 21:123-144 (1941).

Parallel with the principal experiment described above, trials of shorter durations were conducted. While results in these trials were generally in agreement with those of the principal experiment, the following two major findings were reported:

- (a) In one area with sandy soil, the yield was less with intermittent irrigation during the two consecutive years of the trial.
- (b) The yield comparison was more variable with other rice varieties.

Several trials of intermittent irrigation have been carried out in China in recent years with generally promising results. Soil characteristics were again shown to be an important factor affecting the applicability of the method. In China, the wet-and-dry cycle was operated by applying water to the fields once in a given number of days and letting it dry up naturally. This greatly simplified the intermittent irrigation practice and eliminated any possible wastage of water through drainage.

Intermittent irrigation may prove to be an effective method for the control of vector mosquitos in ricefields and should be given due consideration. Its success depends on how carefully the relevant factors are studied and the operations planned. When planning, consideration should be given to soil texture, irrigation methods and facilities, water availability, variety of rice, the agricultural practices including fertilizer requirements, species of mosquito vectors breeding in the ricefields and their role in the disease transmission, etc. Field trials must therefore be carried out in close collaboration with the agricultural authorities to establish the applicability of the method under local conditions. These trials will also demonstrate the usefulness of intermittent irrigation for purposes other than vector mosquito control, so that the rank and file farmers will make it a standard practice.

There are genera of pest mosquitos (such as Psorophora) which seek the drained fields for depositing large numbers of eggs on the soil. Reflooding may be followed by the hatching out of heavy populations of fiercely biting mosquitos where this species is present. The potential problem of pest mosquitos should be borne in mind when considering intermittent irrigation for vector mosquito control.

3.7 Other methods of control

It has been variously reported that ricefield mosquito control may be accomplished by introducing larvivorous fish or by routine application of larvicides to incoming irrigation water or to the field surface to be flooded. These measures have value but are temporary, repetitive, and expensive in the long run.

A method of restricting malaria transmission in rice-growing areas by "dry belting" villages is described in Chapter V, section 4.

4. Strategies applied to the control of vegetation in mosquito breeding habitats

4.1 Relationship of plants to mosquito breeding

In reservoirs and natural ponds, three major groups of littoral herbs are found — terrestrial, wetland, and aquatic. Terrestrial herbs are those typically growing in relatively dry soil and usually unable to survive a month of partial but continuous inundation during the growing period. Wetland herbs are those typically growing in soil which is saturated during the major portion of the growing period and are usually not adversely affected by partial inundation throughout that period. Aquatic herbs are those growing in soil covered with water, whose development is inhibited by extended periods of dewatering during the growing period.

4.1.1 The "intersection value" concept

In section 1.3 of this Chapter, water level management in impounded water was discussed as a strategy for the destruction of mosquito larvae, but a second and even more important effect is the stranding of floatage and inhibition of marginal plants which provide the essential aquatic environment for eggs and larvae. The strategy consists in altering the environment in a way which, while not actually killing eggs and larvae, exposes them to the play of natural processes and to predators such as fish, beetles, and dragon fly naiads.

The "intersection value" concept has generally been accepted as an index of the suitability of a habitat for the breeding of *An. quadrimaculatus*. It is based on the fact that the perimeter of a floating mass of leaves and debris has a major effect on the development of mosquito larvae to adulthood.

The "intersection value" is defined as the length in meters of intersection (floatage-air-water) at the plant interface per m^2 of water surface. For example, if twelve lily pads, 20 cm in diameter, float on one m^2 of water surface, the intersection value is calculated to be:

$$\pi \frac{12 \text{ pads}}{m^2} \times \pi \times 0.20 \text{ m} = 7.54 \frac{m}{m^2} \text{ (or } m^{-1})$$

which characterizes the floating leaf as a poor breeding habitat for anophelis mosquitos. If the number of pads is small, the larvae in an array around the floating leaf are easy prey. If the number of pads per m^2 is large, the entire surface of the water may be largely unavailable for mosquito production and the intersection value is extremely small because the length of the plant interface is largely reduced by overlapping leaves (see Fig. IV-6). The seriousness of the floating leaf type of aquatic plant lies in its ability to colonize large areas of relatively deep water, thereby offsetting the low intersection value by the large surface available for producing mosquitos.

It is necessary also to investigate the importance of the intersection value for other malaria vectors which, unlike *An. quadrimaculatus*, breed in fresh water pools, brackish marshes, or streams. *An. minimus*, an important vector in Asia, is a stream-breeding species which is also found in irrigation channels and ditches. The season of peak breeding is at the beginning and end of the rainy season when each habitat has a peak intersection value. In Malaysia, Assam and elsewhere, the clearing of small ravine streams of trees and vegetation (thus exposing the water to sunlight) results in an increase of *An. minimus* and epidemic malaria. The sunlight encourages semiaquatic growth which impedes the natural swift flow of hill streams and protects the mosquito larvae from predators. The intersection value is very much higher than in deep shade conditions. The role of automatic flushing of such areas in lowering the intersection value is discussed in section 5 below.

4.1.2 Specific plant-mosquito relationships

In a few specialized situations, the presence or absence of a malaria vector depends upon the existence of a particular type of plant. The natural cavities of epiphytic bromeliads are the exclusive breeding place for the *Kerteszia* group, including *An. bellator* in South America and the Caribbean. Other cavities such as coconut husks and shells, cut bamboo and the axils of leaves of banana and hemp are associated with mosquito breeding. The genus *Mansonia*, which is responsible for rural filariasis in certain parts of Asia, is almost completely dependent upon the presence of a specific plant. The breathing tube or siphon of *Mansonia*, unlike those of most mosquito larvae, pierce the air-carrying tissues of certain aquatic plants instead of the water surface.

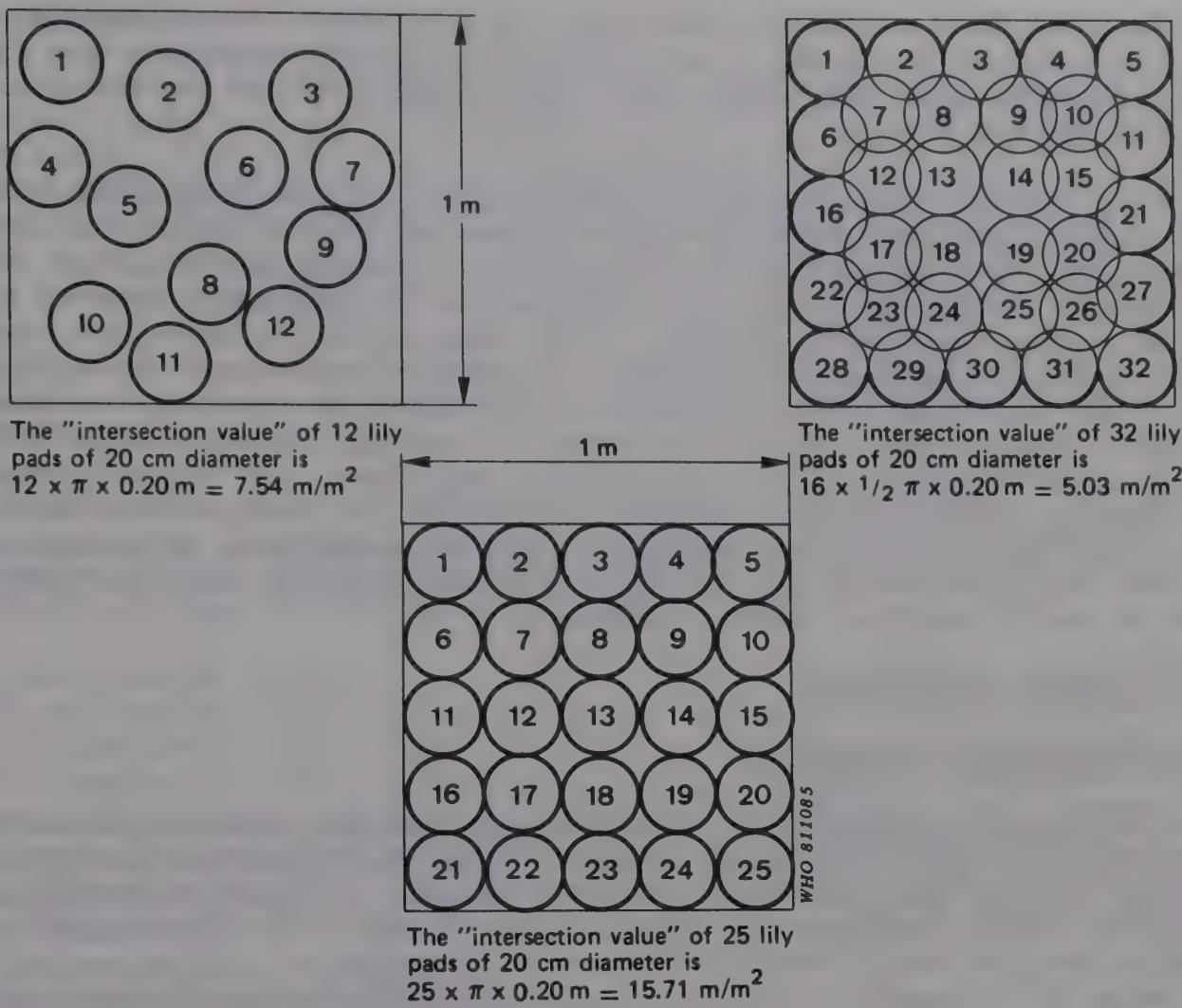


Fig. IV-6. Illustration of the "intersection value" concept.

The "intersection value" increases with the number of lily pads until it is maximum when the surface is filled without overlapping; with further increase in the number of pads, overlapping is produced and the intersection value decreases until the whole surface is completely covered with lily pads and the intersection value becomes zero.

A good example of selective plant strategy is the control of "bromeliad malaria" in Trinidad. The cacao plantations were interplanted with "immortelle" trees (*Erythrina*) to provide shade. An invasion of forest bromeliads plagued the shade trees and allowed the breeding of large numbers of malaria vectors. The control strategy was to destroy all the bromeliads within mosquito flight range of the villages, by hand removal, chemical herbicidal spray, or selective clearing of shade trees. Chemical methods were effective, but in the long run the best solutions were to plant shade trees, such as eucalyptus, which do not support the growth of bromeliads, or else plant the cacao trees close together to provide their own shade.

4.1.3 Plants which allegedly inhibit mosquito breeding

A notable group of so-called antilarval plants includes the muskgrasses (*Chara* and *Nitella* spp.), floating-leaf watershields (*Brasenia*) and bladderworts (*Utricularia*). The first two are rooted submerged types which allegedly give off chemicals to the water while the bladderwort is a carnivorous plant which is able to trap larvae into bladder-like structures. The low intersection value of both of the submerged plants would not suggest heavy anopheline breeding in the first instance. Even if they are truly antilarval, it is questionable whether

sufficiently heavy stands can be established when they are needed. These types do not thrive where anopheline breeding is heaviest, namely, shallow areas with vegetation that is flexuous, emergent or in floating mats. They prefer clear water, exposed to the sun and of too great a depth for rooted emergent plants.

The floating leaf has a low intersection value and can, in some instances, cover the entire water surface. The watershield pads actually overlap like shingles on a roof and, in addition, the wetted parts have a gelatinous film that is unattractive to larvae. The duck-weeds Lemna, Wolffia and Spirodela also form dense mats which completely cover the water surface so that mosquito breeding is minimal. Field observations, however, show that thick pleuston (i.e., small but macroscopic organisms like duckweed) will cover the surface of the deeper water of the pond which ordinarily would not have mosquito breeding. Considerably more and more reliable data are needed on the usefulness of promoting new plant types since no one can predict the outcome in the event the introduced plants "take over" the environment. With only partial coverage, the lily pad or duckweed "lid on the pot" concept might become a regrettable misapplication of natural principles. That it is dangerous to generalize is shown by the fact that high densities of An. sacharovi in Turkey have been associated with Chara, a plant claimed to inhibit mosquito breeding elsewhere.

4.2 Water manipulated as herbicide

4.2.1 Required scientific information

The most serious plant invasions of reservoirs and lakes are caused by wetland and aquatic plants that give high intersection values or those that extend the area of mosquito production either because they grow in deep water or because they have an extraordinarily rapid spread. The control strategy will depend on whether the plant is native or introduced. Native plants seldom give rise to explosive colonization because of existing natural factors. On impounded water it is possible to discover dangerous imported species before they spread too far. In the absence of the necessary scientific information, unsuitable treatment may aggravate and extend the problem. There are numerous examples of this.

To develop a strategy of plant control by natural techniques, a minimum of knowledge must be obtained on the following:

- (a) The natural distribution of the species.
- (b) The intersection value or anopheline breeding potential.
- (c) The optimum habitat. Information is required on the plant's habitat, including the kind of water, whether fresh or brackish, depth of water, preference for shade or sunlight, bed characteristics, and resistance to wave wash.
- (d) Reproductive dispersal and migration potentials. In some plants, such as the water hyacinth (Eichhornia crassipes), the propagation is asexual by offsets of small new plants. When small plants are broken away from the main colony, each can start a new colony until bank-to-bank invasion is complete. It has been observed that a single plant of E. crassipes can give rise to 3000 plants in 50 days.
- (e) Previous control experience. Previous control methods may include mechanical removal and crushing, use as fodder for animals, or the use of herbicides. It is important to know the role of seeds, the possible effects on the plant of water manipulation, and whether the plant has any natural enemies.

4.2.2 Seed germination

Almost all seeds of the woody plant species involved in mosquito breeding habitats, including those of aquatic trees such as cypress, must be stranded or dewatered before germination takes place. This is a feasible control mechanism since the seeds float and can be stranded where their growth would not be objectionable or where competition from existing species would shade out the seedling. If the seeding time is known, a strategy of water management or other control technique can be devised. It is thus possible to keep willow seedlings in a narrow band high in the fluctuation zone of controlled water resource projects.

Almost all seeds of annual terrestrials can germinate only when dewatered. The maintenance of a flood stage as long as possible will guarantee cleaner water surfaces when natural or artificial recessions occur.

Many wetland plants require dewatering for successful establishment. This would include Echinochloa, Polygonum, Eragrostis, Cyperus and Ammannia, and prolonged inundation can manage species belonging to these genera. The viability of the water-stored seed, however, can be quite long, up to 70 years in one reported instance.

Unlike the seeds of terrestrials and wetland plants, those of true aquatics show a great diversity in germination. Some may require dewatering, others germinate on the water surface and strand, or soon settle to the inundated bottom. Therefore, the effect of water level management on germination varies according to the particular plant. Temporary flooding, for example, has no effect on the germination of seeds of lotus (Nelumbo) but prevents the development of smartweed (Polygonum) and favours the germination of spatterdock (Nuphar). Temporary dewatering of seeded areas, while not affecting the seeds of lotus, prevents the germination of pondweed (Potamogeton) and promotes the development of wild millet seeds (Echinochloa).

4.2.3 Vegetative methods of reproduction

Many aquatic species do not rely on seeding, but spread from rootstock, runners, or stolons, or by fragmentation. The stumps of woody plants do not sprout when under water. When dewatered, the ability to sprout will depend on the water tolerance of the given species. Old stumps will not sprout as well as young stumps of the same species. As a general rule, woody and terrestrial herbs are destroyed by prolonged flooding and are injured by short periods of inundation.

Aquatic herbs survive continuous flooding for periods and at depths that are limited for each species. Lotus, for example, can be "drowned" by rapid flooding in 12 days, whereas root stocks are not affected by depths up to 2.5 m. Dewatering of perennating structures has no effect on woolgrass (Scirpus), but holds back pondweed (Potamogeton) and promotes the sprouting of maiden cane (Panicum).

4.3 Practical application

4.3.1 Shading by tree planting

Early workers in malaria control believed that shade was important in limiting anopheline mosquito production. Shallow waters exposed to direct sunlight have a more abundant growth of emergent and microscopic plants, thus providing necessary food and protection for mosquito larvae. The larvae of a few anopheline species (such as umbrosus, punctimacula and leucosphyrus) prefer the deeply shaded areas, but those of the more important vectors of malaria prefer some sunlight. Shading by tree planting has been demonstrated to be useful in the control of anopheline species such as gambiae, funestus, quadrimaculatus, fluviatilis, minimus, and sundaicus. Some experimental demonstrations of the method have proved successful. It was thought that selective preparatory clearing could leave stands of water-tolerant trees such as bald cypress (Taxodium distichum) and tupelo gum (Nyssa aquatica) in shallow waters of impoundment sites, but it was found that these species were "drowned" on flooding and failed to survive. In southeastern USA it was shown, however, that the transplantation of

nursery seedlings of these same species into shallow water sites in reservoirs, despite a difficult initial growth period of 2-3 years, eventually succeeded in obtaining a measure of mosquito control through shading.

In 1967 and 1968, some 32 years after planting, the control of anopheline breeding in these tree plantations was evaluated by examining larval density within and outside the artificially shaded areas. The results were as follows:

<u>Area</u>	<u>Dips taken</u>	<u>Total anopheline</u>	<u>No./100 dips</u>
Shaded	3085	95	3
Open	1680	308	18

In addition to the planting of seedlings, shading of stream banks has been provided with cuttings of the thorny Duranta sp. in Assam. Species of Eucalyptus, Ficus and Terminalia have been used for shade purposes throughout the tropical world. Willow (Salix) and cottonwood (Populus) are commonly employed in waterlogged areas of irrigation systems. Tree planting on irrigation canal banks should be avoided, however.

4.3.2 Artificial flooding

Artificial flooding, even to a depth of 30-40 cm for a period of one month, is unable to kill the seedlings of marginal plants once they have attained some elongation, except in very few cases. The exceptions are ragweed, (Ambrosia), cocklebur (Xanthium), goldenrod (Solidago), crabgrass (Digitaria), and other herbs which follow the receding water. The aim of vegetation control by flooding is to keep the seeds and perennating structures under water to prevent germination or sprouting before natural recession begins. When flooding completely covers the margin so that no plant extends above the surface, drowning takes place in a few weeks for most annual species. The seeds, rootstock and floating stems are thus prevented from renewing colonies. The depth and duration of flooding is variable for different plants. Almost all are killed by inundation for one growing season (about 200 days), but some aquatics such as lotus can be destroyed in as short a time as 2 weeks. The difficulty is that deep flooding of natural areas is usually not of sufficient duration to control more than a few plants. In impounding reservoirs in tropical countries it is likely that all rooted aquatics and almost all annual plants can be controlled by the wide progression of pool levels as the annual flood waters are collected.

4.3.3 Cutting and flooding

In ponds and canals where great depths of inundation are not obtainable even during flood periods, it is a useful practice to cut the plant and submerge the rootstock, instead of shallow flooding the entire plant. The plants that respond especially well to this cut and flood treatment are mainly monocots and include rush (Juncus), giant cutgrass (Zizaniopsis), woolgrass (Scirpus), and cattail (Typha). These plants must be cut during the growing season, preferably before seeds have developed. About one week of continuous shallow flooding of cut stubble will give excellent control. Cutting is facilitated by low water levels. Narrow inlets to ponds and sloughs can be used for plant control by erecting temporary dams for impounding water over the stubble.

4.3.4 Recurrent cutting

The theory of recurrent or repeated cutting of a plant for control is based on the fact that the ability to send out perennating structure is limited. Hibiscus and cattail can be controlled without flooding by cutting the plant two to three times during the growing season. After each cutting the number of resprouts will be markedly diminished. Deep water floating leaf aquatics such as lotus, water lily, and water chestnut (Trapa) are cut in standing water.

Repetitive cutting of the food-producing structures (leaves) will deplete the food reserve in the rootstock. The depth and turbidity of the water is a factor. New colonies of lotus, for example, can be controlled by one or two cuttings in relatively turbid water 1 m deep. Small areas may be controlled by hand snapping of the petioles. For larger colonies, underwater mowing machines (designed for this purpose) may be employed. These floating units can cut 1 to 2 hectares per day provided that the water is at least 0.5 m deep and there are no stumps and snags.

4.3.5 Special mechanical methods

Many aquatic plants are spread by fragments which break off from the parent plant, float to a new location, and take root. Some plants of this type are alligator weed (*Alternanthera*), water primrose (*Jussiaea*), and Eurasian milfoil (*Myriophyllum*). Attempts to control such plants by mechanical raking, rolling and crushing may defeat their purpose by producing hundreds of small reproductive fragments. Mats of floating water hyacinth and alligator weed have to be mechanically removed and deposited above the water line. Most of the hyacinth will die but alligator weed roots near the waterline will resprout. These procedures are only temporary and expensive means of keeping navigation channels open.

Cutting or grubbing below the root crown is an effective method for eliminating woody plants such as willow and buttonball, which do not resprout from the roots. Willow propagation is by seed and by branch cuttings, but not from stumps or stubble cut below the root crowns. Mowing down or hand cutting of willow above the root crown increases growth since multiple sprouts are produced from each stem cut. One blow of the axe delivered by a trained worker below the ground line will permanently eliminate the plant. The technique is applicable when thinning out the willow thickets used to produce marginal shading for mosquito control purposes (see section 4.3.1).

4.3.6 Dewatering of aquatic species

Although, as mentioned in section 4.2.2 above, the dewatering of many marginal plants promotes seed germination and resprouting, it is an effective means of controlling certain of them. True aquatic species are often killed or damaged by dewatering. This is especially true in the temperate zone where dewatered plants may be subjected to freezing weather. Water primrose which, unlike alligator weed, does not sprout from the roots may be effectively controlled by dewatering in the winter season. Where wide ranges of drawdown are part of the annual cycle, the rooted floating mat type of plant should present no major problem. These rooted plants cannot sprout if at a depth of 1 m and do not thrive on dry land above the waterline. The cycle of wide recession will thus control most mosquito breeding in marginal vegetation. Reservoirs in tropical countries which operate at nearly constant level all year round may have no alternative to using chemical measures to control such breeding.

An unfavourable habitat may be created for other than the rooted floating mat aquatic species by deepening and filling techniques, which may aid in mosquito control in pools of nearly constant level. The cut zone is too deep for the aquatic species and the shoreline too steep to give any sizeable area of mosquito production. Therefore, the depth of water tolerance is one of the most important plant characteristics to be considered in efforts to control aquatic plants. This technique of topographic alteration by filling and deepening (see subchapter IIIA) is particularly useful for fish ponds and sewage lagoons.

5. Stream flushing

5.1 Antimosquito action

Some of the important vectors of malaria in tropical Asia are fluvial or stream-breeding anophelines. The intensely domestic vector *An. minimus* prefers the edges of gently moving, clean, clear water streams. Its ideal habitat is found in small streams after the heavy rains have terminated, when the relatively low flow is largely cool clear ground water with grassy margins. The larvae have difficulty staying in the desired habitat if the velocity exceeds

8-10 cm/sec. This is one reason why a large river with considerable natural water fluctuations and deep shaded margins is less favourable to mosquito breeding than small streams are. Significant tropical stream-breeding vectors include the anopheline species minimus, flavirostris, fluvialis, maculatus, superpictus, varuna, pseudopunctipennis and sergenti.

It is well established that little mosquito breeding is found in any stream, big or small, that has widely fluctuating water levels with occasional overflowing of the banks. A swift, muddy, turbulent flow, devoid of emergent vegetation, is not an ideal larval habitat. The larvae of only a few hardy fluvial mosquitos can hold onto overhanging vegetation or remain in eddy places long enough to complete a life cycle in such conditions. Adult mosquito populations do not increase in geometric progression until after the peak rainfall has passed.

When a sudden flush of stored water is released into the breeding stream channel, and this is repeated periodically, the larval habitat is altered in several ways. These short periods of increased water velocity may (a) dislodge and expose larvae and eggs; (b) stir up the bottom sediments which may bury mosquito instars; (c) produce a wave-front water fluctuation cycle which assists in dislodging and perhaps stranding larvae; and (d) check the invasion of the marginal vegetation that reduces stream velocity and provides protection for larvae. The literature suggests that mechanical force is the major antilarval action but turbulence is observed only in the zone immediately downstream of the point of flush water release. The inhibition of plant invasion seems to be the most observable antilarval mechanism produced by periodic flushing. The well flushed stream does not have any good places in which to "dip for larvae".

5.2 Dry streambed breeders

The larvae of a number of anopheline species such as culicifacies, albimanus, pattoni, and argyritarsis are found concentrated in the pools of drying stream beds. These are, for the most part, true lacustrine species and it is doubtful whether the technique of periodic flushing, even if practicable, would provide adequate control. As the dry stream bed usually still contains a long series of ground depressions filled with water, each flush would require considerable volumes of water, thus making a great demand on the storage reservoir which might well exceed the available inflow. The conclusion is that, for any considerable number of breeding pools, such as might be found in wide river beds, sluicing would not be massive enough to destroy the larvae. The possible exception would be the use of large-head water storage reservoirs designed for other purposes than mosquito control. Recently in Sri Lanka the emergency release of water from such a reservoir was considered necessary in malaria control operations.

5.3 Rational design of flushing

5.3.1 Inflow at peak breeding

It has been observed that to have a well flushed stream, flushing should start at the beginning of the breeding season with a cycle as short as one flush per hour and should end when the stream is drying up with only one flush per week or longer. It is mandatory that at least one or two flushes per day be provided at the time of peak mosquito production. When the inflow into the storage reservoir is insufficient to compensate for the outflow required for one or two flushes per day, it will be difficult to distinguish any difference in habitat and larval densities between flushed and unflushed streams. This demonstrates the relationship between the stream inflow at the time of peak mosquito production and the hydraulic design of the flush cycles. If these elements are not balanced, the scheme will fail.

In Fig. IV-7, the relationship is given between rainfall, runoff and the production of adult mosquitos of the vector An. minimus flavirostris. The adult catches throughout the year are monthly averages per trap, which was baited with a carabao ten hours per week. The relationship shown is typical for fluvial vectors with a peak number of adults after the rains have ceased and when the recharged groundwater level provides a near constant stream flow of clear water. In this situation, the inflow for flushing design is taken to be about 0.11 l/s

per hectare of drainage area. In some tropical areas where the termination of rain is less sharp, twice as much inflow may be appropriate.

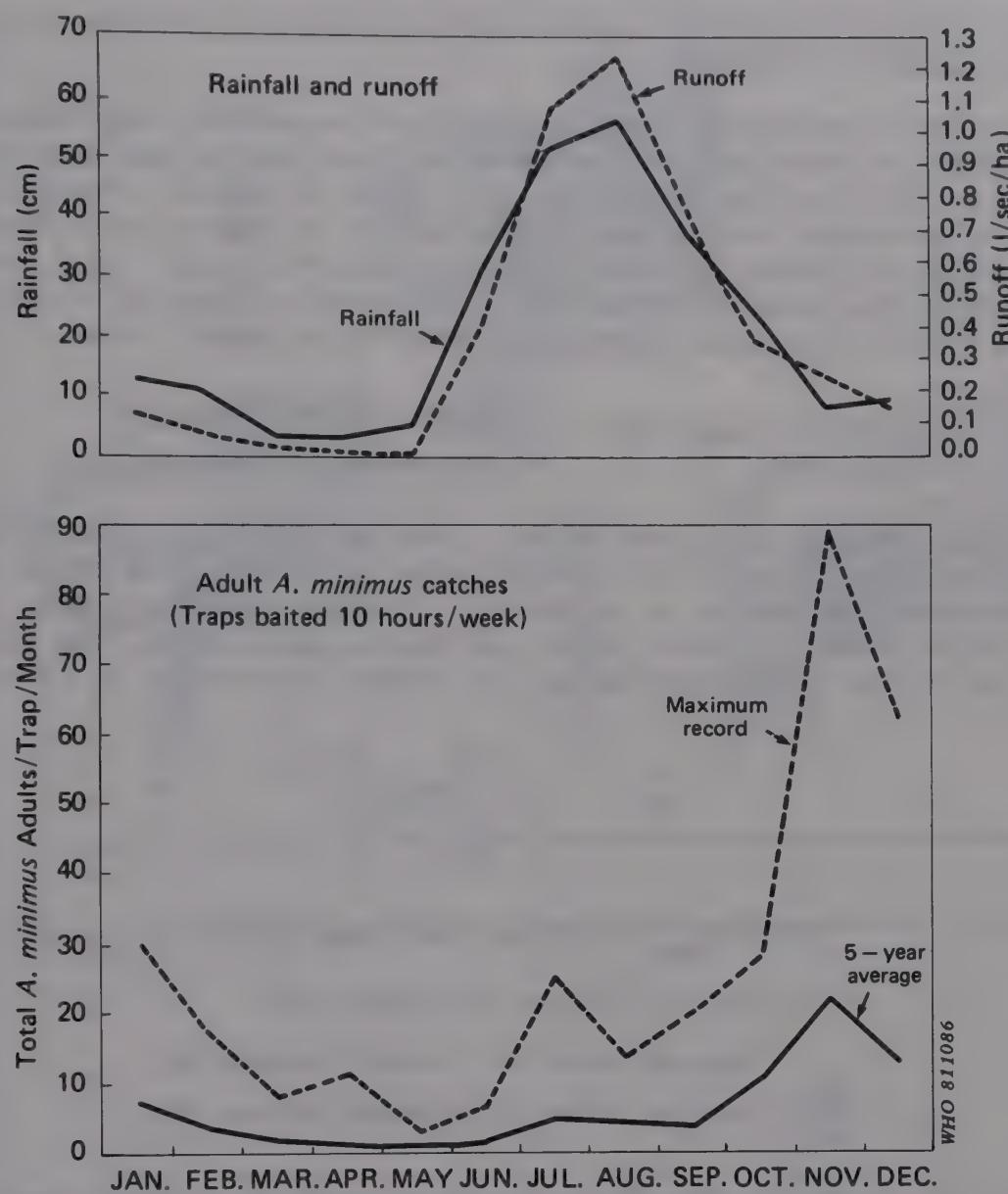


Fig. IV-7. Relationship of wet/dry tropical rainfall and runoff pattern on the production of *An. minimus flavirostris*, the fluvial malaria vector of the Philippines.

5.3.2 Automatic versus manual flushing

Many experienced workers prefer the manual sluice gate which is simple and easy to maintain. Automatic devices, whether self-priming siphons or tipping buckets, are not easy to design, construct or maintain properly. Even the simpler automatic devices require frequent visits by field people to ensure proper operation during the critical breeding season. As that period approaches, siphons must be carefully checked, silt gates closed, any leaks in the crown repaired, and blockages cleared in the priming vents. Floatage in the reservoir must be removed.

The disadvantage of the manual sluice is that more than two flushes per day may be difficult to operate every day throughout the breeding season if many sites are involved and manpower is limited. For example, one village required the operation of 13 sluice gates to provide protection in the area within the 1.6 km mosquito flight range.

Automatic devices working day and night are best for altering the stream habitat and controlling mosquito breeding. When stream flows abate, a series of dams on a single stream can provide successive flushes using the same flushing volume in turn with limited waste.

5.3.3 Downstream distance of control

Until recent work in evaluating the design and performance of many existing siphons in the Philippines, no significant body of knowledge on flush design was available. The control of fluvial vectors by flushing was accomplished by trial and error. Various investigators determined the flush discharge not so much on the inflow at time of peak breeding, but rather on a critical velocity for larvae control, V , of at least 0.44 m/s. Thus, the discharge rate (Q) in m^3/s = cross-section area of stream (m^2) x designed velocity ($V = 0.44 \text{ m/s}$). The distance of larvae control in metres downstream could be estimated to be:

$$\text{Control length (m)} = \frac{\text{Storage volume/flush (m}^3\text{)}}{\text{cross-section area (m}^2\text{)}}$$

Since the stream cross-section area (width x average depth) is fixed, the downstream control length varies directly with the storage volume available. As might be expected, field observations made during the passage of a flush in a stream revealed a wide variation in velocity as the rush of water traversed pools and shoals downstream. The estimate of effective distance (D_m) of antilarval flush derived from the field observation of 13 different installations is

$$D_m = 213 \left[\frac{Q_{\max} V}{W^2 S^{0.5}} \right]^{1/3}$$

where Q_{\max} = maximum discharge (m^3/s)

V = storage volume per flush (m^3)

W = average width of flushed stream (m)

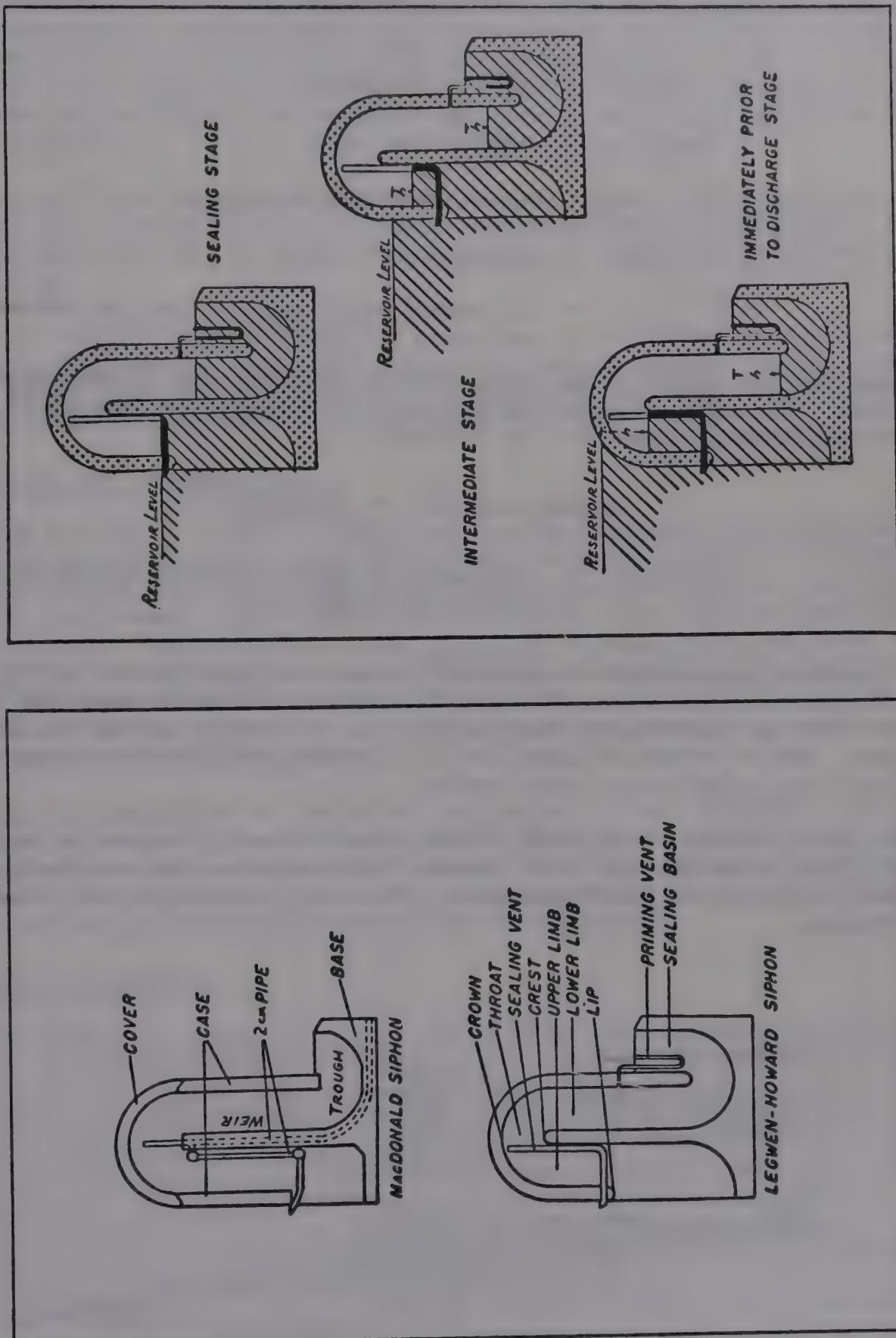
S = average slope of flushed stream (%)

A comparison of estimates obtained from the above empirical formula and the computation of the ratio, storage volume/stream cross-section, gives fairly good agreement considering the rough approximation of the elements employed in the calculation. The greatest disagreement is for the wide streams with slight gradients, where the average depth is most difficult to determine.

5.3.4 Automatic self-priming siphons

The advantage of the automatic siphon for antimosquito flushing lies in the self-initiating and self-arresting features which give the repeated environmental disturbance that inhibits the establishment of an ideal larval habitat. Fig. IV-8 shows two basic types of self-priming siphons. In both, the reservoir water level rises as the inflow is stored until it reaches the lip of the upper limb and seals the siphon. The sealing basin holds air within the siphon and the priming cycle begins. In the MacDonald scheme, the water reaches the level of the auxiliary pipe and escapes through it, ejecting air from the crown and creating a partial vacuum. As the ejection of air continues, the vacuum within the siphon increases so that when water spills over the crest, full prime and discharge starts without excessive loss of water. The Legwen-Howard type wastes no water in priming. Contrary to the vacuum principle of the previous type, priming is effected when the air sealed in the siphon is compressed by the rising water levels. This is possible because of a rather deep sealing basin.

Fig. IV-8. Basic types of self-priming siphons used for periodic stream flushing for malaria control.



The priming time in minutes has been determined for prototypes and laboratory models of the MacDonald siphon. In the field, it is not possible to prime it if the inflow (q) is less than 0.7 l/sec. In this respect, the Legwen-Howard type has an advantage. The estimate of priming time (tp) is obtained from the following formula:

$$tp = \frac{KV_a}{60(q-0.7)}$$

where tp = priming time (min)

V_a = volume of entrapped air (l)

q = inflow (l/s)

K = air removal efficiency (25 for the MacDonald siphon)

It may be seen that the priming time varies directly with the size of the siphon and inversely with the inflow. By rearrangement of the priming time formula, the size of the siphon for a maximum 60-minute prime is found to be as follows:

$$\text{Siphon area (m}^2\text{)} = \frac{3.60(q-0.7)}{K(0.91+h)}$$

where h = difference of water elevations at the entrance and exit of the siphon (m)

When a standard cross-section is developed, several siphons placed side by side and at precisely the same level can be used to give the required discharge head. For existing siphons, the discharge coefficients range from 0.4 to 0.2 because air is not entirely removed from the crown. Smooth curves are expensive to form and give little improvement in discharge characteristics over cheap square corner designs.

As the fluvial vectors breed mainly in the monsoon zones, dams must be so designed and built as to ensure protection from flood damage. Silt gates must be open during floods and sites carefully selected for good foundations. Fig. IV-9 gives structural details of a dam and siphon design.

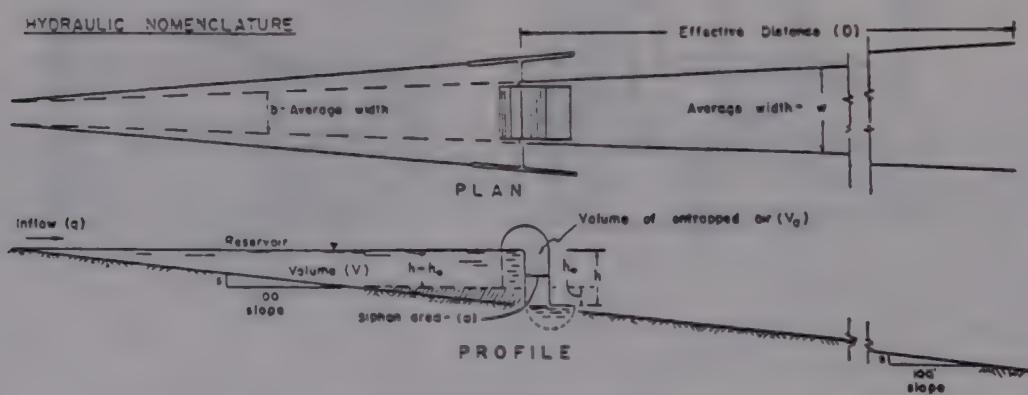


Fig. IV-9. Design of dam and siphon for intermittent flushing.

5.3.5 Design procedure and example

The minimum data for a preliminary design of a stream flushing system include the profile and width of the portion of the stream that is less than 1.6 km (mosquito flight range) from the village to be protected. The drainage area contributing to the flow must be estimated from maps or in the field. The location of the first dam and siphon is fixed at about 1.6 km upstream from the village. The practical maximum and minimum discharge heads are determined so as to leave some dead storage in the reservoir for fish or other purposes and ensure that the pool will not overflow.

After the storage volume and the area of cross section for the siphon have been calculated and estimated, the assurance of flush cycles at the design inflow is examined. The minimum siphon discharge in order to ensure interruption must be checked to conform with the requirement $Q_{\min} \geq 2q$.

The location of the next dam downstream is determined by the effective flush distance (540 m from dam 1 in the example). In this step-by-step design, siphon sites are added until the reach within flight range has been covered by antimosquito flushing. It is convenient to present the calculations in tabular form, as illustrated in Table IV-1.

6. Coastal flooding and impounding

The principles of deep or shallow flooding have already been described as elements of water management on impoundments or on flowing streams. The general subject of aquatic plant management was discussed in section 4 above and the same techniques apply to a certain extent to the marine water environment. This section will deal with the control of brackish coastal marsh anopheline vectors. These species include sundaicus in Asia, melas and merus in Africa, labranchiae, atroparvus and sacharovi in the Mediterranean, and albimanus, aquasalis and grahamii in the Americas. None of these species can develop in the salinity of the open sea; they find their breeding habitat in landlocked marshes and swamps whose natural connexion with the sea has been closed by wave action.

It is difficult to generalize on the pattern and range of tides throughout the tropical coastal islands and continents. The difference between the high and low levels of a tidal cycle can be as much as several metres or as little as 0.5 m (or even less). A strong tide will almost dewater a well drained salt marsh below the vegetation line. A weak tide will produce much less difference in ecology between high and low points.

6.1 Open marsh water management

In the United States and elsewhere, a high degree of natural salt marsh management has been developed for beneficial purposes including mosquito control. No malaria mosquito problem exists, but the salt marsh Aedes mosquitos create a very difficult problem. The peculiarity of this group of mosquitos is that they deposit eggs on the moist earth in depressions close to the high point of the tides. The eggs can remain viable for several months. The eggs are hatched when rain storms or high tides flood the area. There is essentially no breeding in the lower marsh elevations and the mosquitos all breed at the ecological contour as defined by salt hay (Spartina patens) and reeds (Phragmites). Generally, the strategy is to restore the tidewater fluctuation to all isolated pools and depressions. Mosquito control consists of flushing the larvae from protective cover, stranding them, altering vegetation, and destroying larvae by exposing them to predators or to the circulation of raw cold sea water. The open marsh management techniques that are adequate for Aedes control will be more than adequate to reduce Anopheles breeding.

The practice of diking, draining and excluding the tidal action on salt marshes (see sub-chapter IIIE, section 4.1.1) is not recommended when there is a risk that the entire marsh area will be invaded by salt hay and other semiaquatic species, resulting in heavy production of mosquitos in rainwater pools and depressions. Restoration of tides into the marsh will "drown out" the undesirable marsh grasses and reestablish them at the top of the high tide

zone where larvae may be controlled.

Table IV-1. Sample calculations for suggested design procedure.*

- Item	Dam 1	Dam 2	Dam 3
1. Data:			
Siphon discharge head—ft.— h	4.0	5.0	6.0
Siphon minimum head—ft.— h_0	0.5	1.0	1.0
Drainage area to siphon—sq. mi.	0.1	0.3	0.6
Stream slope at res. site—%— s	0.02	0.015	0.008
Stream width at res. site—ft.— b	3.0	4.0	8.0
Downstream slope—ft./100 ft.— s	2.0	1.0	0.5
Downstream width—ft.— w	3.0	5.0	8.0
2. Volume per flush (V)			
$V_t = \frac{h^3 + h^2 b}{2s}$ cu. ft.	2,800	7,500	32,400
$V = V_t - \frac{V_t h_0^2}{h^2}$ cu. ft.	2,756	7,200	30,900
3. Inflow (q) sq. mi. $\times \frac{c.f.s.}{sq. mi.} \times 60$ c.f.m.	6.0	18.0	36.0
4. Siphon cross section (a) $a = \frac{60(q - 1.5)}{25(3 + h)}$ sq. ft.	1.54	4.95	9.3
5. Siphon discharge Q			
$Q_{max} = 0.4a \sqrt{2gh}$ c.f.s.	9.9	35.5	72.0
$Q_{av} = 0.3a \sqrt{\frac{2g}{2}} h$ c.f.s.	5.2	18.9	38.6
$Q_{min} = 0.2a \sqrt{2gh_0}$ c.f.s.	1.7	7.9	14.9
6.			
Filling time V/q min.	460	400	860
Priming time 60 min.	60	60	60
Discharge time $\frac{V}{60Q_{max}}$ min.	9	6	13
Total time of cycle	529	466	933
Cycles/day $\frac{1440}{total\ time}$ no.	2.7	3.1	1.5
7. Effective distance— D ft.			
$D = 180 \sqrt[3]{\frac{Q_{max} V}{2w^2 s^{0.5}}}$	1,800	3,100	5,200

* This is an illustrative example of a design procedure; it is irrelevant whether the results are in English or metric units. The figures given are of value as examples only.

Another application of open marsh strategies where the topography is flat is to deepen the marsh by excavating a clean-edged pond to a depth below the low tide level. This will exclude emergent vegetation from the area formerly covered by a series of small grassy pools, which is difficult to drain. All ditches and excavated ponds are connected so that their level fluctuates with the tides. Although anopheline mosquitos lay their eggs on the water surface, the larvae must have emergent vegetation and floatage for food and protection. As in the water level management of impounded water, the tidal cycle of ebb and flow keeps the vegetation zones in natural order, and strands the drift and floatage at the high water mark. The grass-like aquatics of high intersection value will be dewatered at low tide. Some minor problems may arise from the improper construction of spoil banks with material dug out from ditches and ponds.

6.2 Artificial inundation

A marsh can be permanently flooded at a high level, although below the spring tide level, and maintained by dikes and spillways at a constant pool elevation. This procedure of impoundment eliminates suitable places for ground ovipositing Aedes species, but will not prevent the Anopheles from ovipositing on water along the vegetated margins of the pool. It is important to maintain some seawater circulation when the marsh is used for water fowl and wildlife breeding. This is accomplished by letting in the spring tide through spillways set in the dikes enclosing the marsh. The constant level feature of this management is not desirable for control of malaria vectors.

Fresh water swamps may be inundated by damming the outlets, thereby eliminating the original breeding area. Artificial impoundments for water fowl breeding have flooded out the breeding areas of anopheles but where no preparation or water level management was done, it merely resulted in shifting the problem from one area to another. Proposals of this nature should be examined in advance by health agencies to ensure that problems along the new shoreline are controlled.

7. Chemical and physical alteration

7.1 Desalination

As was stated in section 6 above, several vectors of malaria prefer brackish water and several (including Anopheles albimanus) are able to breed in fresh water as well as in salt marshes. Desalination, therefore, should not be undertaken when the brackish water species will also breed well in fresh water. In some instances, the local freshwater vector is more dangerous than the salt-water species. The replacement of An. melas with the fresh water An. gambiae, which tolerates some salinity, will not represent any gain in the control of malaria. This also applies to certain culicine mosquitos.

In coastal areas, salt marshes are often reclaimed for agricultural purposes. This can be done only where an abundance of fresh water is available for wet crop irrigation and for leaching and flushing the excess salts from the soil. In Guyana, sea defences and an irrigation system were built for growing cane and rice. The water resources scheme was highly developed with navigation locks and canals, and hydroelectric power for pumped drainage. Unfortunately, the resulting desalination led to the disappearance of the weak vector An. aquasalis and the propagation of the strong vector An. darlingi, a fresh water breeder. The resulting effect on malaria transmission is shown in the following table:

Coastland Guyana malariometric survey, 1944.
Schoolchildren less than 14 years, spleen rate (S.R.)

Irrigated (desalinated) areas				Salt marsh areas					
	No. on rolls	No. exam'd	No. positive	S.R. (%)		No. on rolls	No. exam'd	No. positive	S.R. (%)
School 1	1393	501	310	62	School 3	2812	300	5	1.7
School 2	1544	192	94	49	School 4	9078	699	14	2.0
Total	2937	693	404	58		11890	999	19	1.9

In the case of the Asian coastal marsh breeder An. sundaicus, it appears that no intensification of malaria transmission is to be expected from desalination measures.

7.2 Salination

The technique of increasing the salinity of a brackish marsh is less risky than the reverse. There have been a number of successful applications involving the enclosure of the marsh by dikes, the diversion of fresh water inflow from the marsh, and the installation of self-closing tidegates which impound the incoming sea water. As evaporation concentrates the salts, the salinity soon approaches or exceeds that of the open sea. No malaria vector can develop in such an environment, although it has been claimed from laboratory tests that An. melas can breed in water with 150% of the sea water chloride content. In addition to the change in water salinity, antimosquito factors include ecological modifications of the water flora and fauna. One such change results from the salt burning of vegetation including mangrove trees. Hurricanes and typhoons can upset these projects by introducing fresh water into the swamp. Maintenance is likely to be rather high with this type of control.

The most convenient tidal area for mosquito control on tropical coasts is the mangrove swamp. The mangrove excludes other vegetation and is the only aquatic tree that grows in the tidal zone which otherwise would be overgrown with coarse marsh grasses. When protected from cutting for fuel, mangroves become large and shade out vegetation. A strong tidal cycle greatly limits the production of brackish water anophelines. Thus, good drainage is all that is needed for control. However, mangrove swamps have been heavily harvested in most populated areas and become isolated from the sea by drainage obstructions. Under these conditions, mosquito breeding is heavy and uncontrolled in emergent vegetation and floating matter lodged in the tree roots. An. melas in coastal Africa is associated with the black mangrove (Avicennia) which grows high in the tidal zone compared with the more aquatic red mangrove (Rhizophora). The best strategy is to plant and not cut mangrove, and thus establish a shady open marsh water management.

7.3 Anaerobic decomposition

The major malaria vectors tolerate a wide variety of chlorides and other chemical substances in the water, but are generally clean water breeders. While culicine species often thrive in polluted waters, anophelines usually do not. The An. gambiae group is one possible exception, although more hard data are needed on this African complex of vectors. An. arabiensis in Nigeria and An. stephensi in India are species that can survive in quite polluted water.

Many streams and pools within villages accumulate human and animal waste and solid refuse. Waters that are black in appearance or bubbly with foul-smelling gases are devoid of anophelines. The septic condition indicates an organic pollution load which depletes the dissolved oxygen in the water. The decomposition by anaerobic organisms is slow and incomplete and with many complex end-products. The following observations have been reported on conditions inhibiting anopheline mosquito breeding:

- (a) Amphibian larvae cannot survive in water of low dissolved oxygen content;
- (b) Vorticella and other ciliates (anaerobic macroorganisms) are indicators of water unfit for Anopheles;
- (c) Decaying matter in beds of artificial impoundments causes them to become oligotrophic (peat bog-like) and poor producers of anopheline mosquitos;
- (d) Many culicines, but very few anophelines, can breed in sewage stabilization ponds;
- (e) Seepage waters high in flocculated iron (Fe_3^+) are unattractive to anophelines.

All of these observations suggest that the anaerobic condition is the controlling factor. However, the risk of spreading an "ecological fallacy" is great if it is assumed that a single factor, such as lack of dissolved oxygen, is the cause of anopheline inhibition.

It is possible to render small ponds and drains unfit for anopheline mosquito breeding by the addition of organic materials of high oxygen demand. The large tonnage required obviously makes this method impractical for large bodies of water. Freshly cut herbaceous plants are the cheapest and most readily available biodegradable material for mosquito control use. The technique consists of either filling and compacting the water space or, in case of a stream, "roofing" at the water surface so that unobstructed flow may be maintained. The natural mechanisms thus brought into operation include depletion of oxygen, decomposition into byproducts, organic bottom sludges, shading and mechanical barriers to oviposition. The measures are temporary since eventually the water will recover from its grossly polluted state. Heavy tropical rainfall will shorten the effective life of the measure.

The use of industrial wastes in either liquid or solid form for altering the pH or toxicity of breeding waters seems deceptively cheap and effective until all implications and costs are examined. The discharge of industrial wastes is liable to dangerous misapplication. If chemicals are to be deliberately added to the water, compounds specifically manufactured and recommended as mosquito larvicides should be used.

The wisdom of polluting water even temporarily for malaria control is highly questionable. It is in contradiction to the principle of water resource conservation and the reverse of a long-term solution. The widespread pollution of urban drains and streams by sewage is not intentional and, while it may limit malaria vectors, remains the principal threat of filariasis and encephalitis transmission as well as transmission of waterborne diseases.

7.4 Physical measures

Most of the physical measures are hydrodynamic in character such as flooding, flushing, fluctuation, wave action and surface agitation. Several of these measures have been dealt with in previous sections. Their main impact is often indirect by making the larval habitat less protective, but they have a direct effect in certain circumstances. For example, top feeding fish can provide excellent control of mosquito larvae in a concrete-lined ornamental pool. The same pool may be controlled by a continuous agitation of the surface water such as that produced by fountain jets. The agitation and wave action produced by the frequent drawing of water from a well is often all that is needed to prevent mosquito breeding. In a natural setting with emergent vegetation, neither of these measures would provide sufficiently effective control.

Water tanks and cisterns might be fitted with surface agitation devices as a measure of mosquito control. A major urban vector of malaria, An. stephensi, breeds in permanent clean water containers. The introduction of piped water has eliminated the need for rainwater cisterns in tropical cities, but the low mains pressure has made numerous roof storage tanks necessary. Insisting on "air broken" instead of submerged inlets for these tanks might free them of An. stephensi by jet water surface agitation and, in addition, reduce the possibility of pollution of the public water system by back siphonage.

The application to rural environments is described in Scharff's Penang Hill demonstration.^a A mountain stream is diverted to small storage pools on each field terrace to facilitate irrigation. Water cascades from upper to lower pools through bamboo pipes which discharge 1 m above the pools' surface. The agitation thus produced is sufficient to control mosquitos in clean-edged pools.

Wave action discourages mosquito development and reduces the marginal vegetation which may protect larvae. Steep shorelines and wide clear reaches intensify the wave action. Deepening and filling techniques in shallow ponds effectively produce the same effect.

^a Scharff, J.W. Anti-malarial drainage from the point of view of the health officer. Penang, Malaysia, Malaria Advisory Board, 1959 (Circular No. 10).

1006

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CHAPTER V

REDUCTION OF MAN/MOSQUITO CONTACT

CONTENTS

	<u>Page</u>
1. Site selection and housing design	154
2. Mosquito-proofing of dwellings	155
3. Land occupancy and use restrictions	158
4. "Dry-belting" villages in rice-cultivating areas	158
5. Individual protection	158
6. Zooprophylaxis	159
7. Basic sanitary measures	161
Further reading list	162

1. Site selection and housing design

It has been observed that the highest concentrations of adult mosquitos occur in the vicinity of their natural breeding habitats and that, in general, mosquito densities diminish gradually as the distance from the breeding site increases. Maximum flight ranges from breeding places have been reported for some species of mosquitos. Few anopheline species travel more than 4-5 km from their breeding places. In the tropics the flight range is usually shorter and in European and temperate zones longer.

If houses and villages could be removed or built away from breeding sites and beyond the normal flight range of the local vector mosquitos, man/mosquito contact and disease transmission would be drastically curtailed. Even when the local vector has a much longer flight range, locating houses and villages 1.5-2 km away from mosquito sources will markedly reduce man/vector contact since only a fraction of the mosquito population will reach the village. This fraction can be controlled by other measures, and will most likely be too small to establish disease transmission. It would be useless, however, to locate a new village 2 km away from an existing major anopheline mosquito habitat if at the same time no action were taken to eliminate or control the minor or temporary breeding foci and to remove or render unsuitable the shelters that mosquitos may use along their flight path.

Certain important mosquito vectors are peridomestic, i.e., they breed and live in the vicinity of human dwellings. They lay their eggs in a variety of natural and artificial water collections, each of which becomes a potential or active focus of mosquito breeding. Some Anopheles are particularly associated with borrow pits, some Culex and Aedes with ditches and drains, and some Aedes with artificial containers. It is thus evident that site selection will not be an effective mosquito control measure unless accompanied by land improvement, general clearing of the immediate surroundings of houses and villages, and basic sanitation development within the community.

Site selection, however, plays an important part in reducing man/mosquito contact. Villages located on high ground and exposed to wind currents are usually freer from mosquitos than those lying at the foot of hills or in enclosed valleys where the air is calmer and water usually more abundant. Prevailing breezes may, however, favour the dissemination of mosquitos and extend their normal range of flight. It is therefore important to locate villages on the windward rather than on the leeward side of breeding places.

The location of villages on higher ground offers the additional advantage of facilitating natural draining of rain water to lower lands thus reducing the effort for surface improvement of the surroundings. Sandy and porous soils which do not easily become waterlogged are preferable for village sites to clayey and impermeable soils which tend to crack and lead to the formation of water pools.

A consideration in housing design is that, providing they have adequate means of access, mosquitos are more frequently and abundantly present in warm, dark and damp places in houses. Dwellings that lack light and ventilation, or have dark recesses, cupboards, old curtains or draperies and much furniture attract mosquitos more than rooms with large windows, bare walls, smooth ceilings and sparse furniture. High indoor mosquito densities have also been attributed to overcrowded occupancy, particularly where it includes small children, and sometimes to the proximity of animal sheds and stables. On the other hand, suitably designed and located stables, usually on the edge of villages between breeding sites and human dwellings, may attract mosquitos away from man and houses (see section 6 below).

It has also been found that at night mosquitos usually approach a house from the leeward side guided by the current of odour-bearing warm air and, for some species, also by the light from the windows.

There is evidence that the situation and size of apertures leading into a house influence the numbers of mosquitos entering it; this subject deserves further investigation.

2. Mosquito-proofing of dwellings

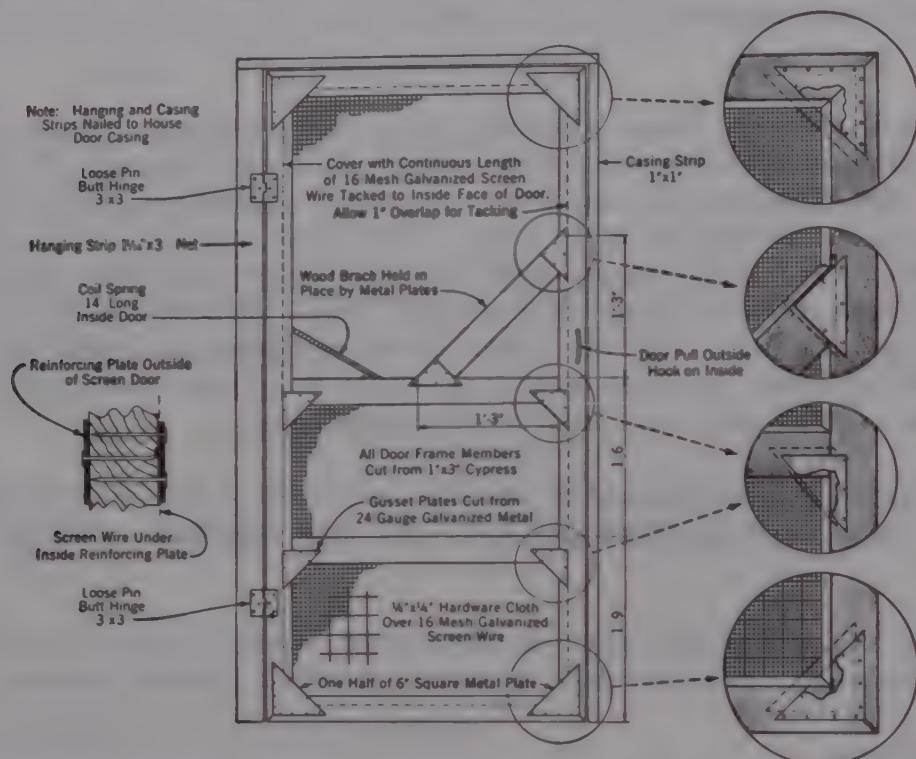
Mosquito-proofing of dwellings for disease control has the twofold aim of protecting man from infective mosquito bites and preventing mosquitos from feeding on infected individuals. There have been instances where a decline in malaria transmission was observed to move parallel with such housing improvement. On the other hand, in the tropics where people remain outdoors until late at night there have been instances where the effect of this measure on disease transmission has been minimal.

Mosquito-proofing involves not only the closure of windows and doors with screens but also the repair of cracks and holes and the blockage of all other openings through which mosquitos might gain entrance. In many parts of the world and especially in the tropics, the nature of human dwellings in rural areas often precludes the application of mosquito-proofing. This is the case where some rural houses are made of thatch with large openings and others consist of a roof without walls. In general, most rural houses in developing countries do not lend themselves to proper screening.

Where mosquito-proofing is feasible, priority should be given to the space where the family gathers in the evening or sleeps at night. In hot climates it may be necessary to screen a portion of the outdoor space in a cage-like frame.

Screening of houses with wiremesh cloth has been in use for over a century and started long before the disease transmission role of the mosquito was demonstrated. It was one factor

associated with the gradual decline of malaria prevalence in USA.^{a,b} The wiremesh cloth should be selected to give adequate protection, maximum ventilation, and long life. Wire screens in humid coastal areas are exposed to the corrosive action of sea air and to vibration induced by strong winds; for such situations, plastic mesh is less liable to deteriorate although for porches and wide openings it may require backing with a welded mesh of thick wire to prevent sagging under the wind pressure. Fig. V-1 shows the construction details of a screen door as installed by the Tennessee Valley Authority. This is given as an example; it can be modified and adapted to suit local conditions.



(Reproduced from:
Malaria control on impounded waters.
 Washington, DC,
 United States Public Health Service,
 Tennessee Valley Authority, 1947,
 p.193).

Fig. V-1. Construction details of a screen door used by the Tennessee Valley Authority.

A very real objection to the extensive use of screens is the fact that they obstruct the passage of air, reduce ventilation, and keep the heat in the room. Tests with 16-mesh monel metal (0.22 mm diameter) and copper and bronze (0.38 mm diameter) screens have shown a reduction in wind passage that ranges from 30-50%. Consequently screens should be selected to provide as much ventilation as is consistent with safety. Wire meshes No. 16 and 18 (16 and 18 wires per linear inch), with respectively 63 and 71 wires per dm, are adequate for most situations. Table V-1 gives the characteristics of commonly used wire cloth.

Before a screening programme is launched, the population concerned should be informed about the protection this measure offers against disease transmission and annoyance by mosquitos. Studies should be made of people's behaviour, habits, tastes, preferences, desire for change and ability to adapt to it. Housing design and construction should conform with

^a Boyd, M.F. The influence of obstacles unconsciously erected against anophelines (housing and screening) upon the incidence of malaria. American journal of tropical medicine, 6:157 (1926).

^b Byrd, H. Mosquitos: role of certain species in prevalence of malaria. New Orleans medical and surgical journal, 67:1417 (1914).

Table V-1. The relationship between the diameter of wire and the apertures in wire cloth of No. 14, 16 and 18 mesh

Width of aperture Nearest ISO sizes (mm)	No. 14 mesh			No. 16 mesh			No. 18 mesh		
	Wire diameter (mm)	Open area (inch) (%)	Wire diameter (mm) (inch)	Open area (%)	Wire diameter (mm) (inch)	Open area (%)	Wire diameter (mm) (inch)	Open area (%)	
1.12	1.17	0.046	0.63	0.025	41.4	0.016	54.1	0.23	0.009
	1.19	0.047	0.61	0.024	43.3	0.015	56.5	0.20	0.008
	1.22	0.048	0.58	0.023	45.2	0.014	58.9	0.18	0.007
1.25	1.24	0.049	0.56	0.022	47.1	0.013	61.5	0.15	0.006
	1.27	0.050	0.53	0.021	49.0	0.012	64.0	0.13	0.005
	1.29	0.051	0.51	0.020	51.9	0.011	66.6	0.10	0.004
	1.32	0.052	0.48	0.019	52.9	0.010	69.2	0.08	0.003
1.40	1.35	0.053	0.46	0.018	55.0	0.009	71.9		
	1.37	0.054	0.43	0.017	57.1	0.008	74.6		
	1.39	0.055	0.41	0.016	59.3	0.007	77.4		
	1.52	0.060	0.28	0.011	70.5				
1.60	1.65	0.065	0.16	0.0064	82.8				

(Adapted from: Boyd, M.F. (ed.) Malaria. Philadelphia, Saunders, 1949, p.1189).

the findings of such studies, so that houses are acceptable. New features and installations should be introduced gradually, always together with the re-education of the dwellers. New houses should be designed to meet the requirements for mosquito-proofing.

3. Land occupancy and use restrictions

When the land within the mosquito flight range is sparsely populated, it may be feasible to persuade the inhabitants to move away from the mosquito-exposed zone by offering them, in exchange, lands of equal or slightly greater value to compensate for the expense and trouble of moving. Should this transaction involve heavy purchasing investments, or the people strongly object to leaving their lands, it may be possible to induce them to move only their dwelling sites out of mosquito reach, perhaps by offering them better houses.

The resettlement of people living in an area that will be flooded by the impoundment of water when a dam is built is an unavoidable task for the responsible agency and the operation is included in the programme and budget of the project. The opportunity can be used for moving also the inhabitants of the land belt around the future reservoir away from the shores where mosquito production and disease transmission may be expected (see section 1 above).

When the vector mosquitos are nocturnal feeders, as in the case of most anophelines, it is a wise precaution to interrupt agricultural, recreational and other open air activities near mosquito breeding and resting places in time to vacate the hazardous zone before the mosquitos start being active.

4. "Dry-belted" villages in rice-cultivating areas

In most rice-growing areas the tendency is to use all available land for rice cultivation, the rice fields frequently encircling the villages and towns very closely. Rice cultivation by prolonged inundation is extremely attractive to mosquitos as it affords optimum conditions for massive breeding of some malaria vectors (see Chapter IV, section 3), while the proximity of the breeding place to human habitation allows the continuous transmission of the disease.

A logical but little practised measure for correcting or preventing this situation is to restrict, as much as possible, the use of land surrounding human communities to the cultivation of dry crops which do not require prolonged land flooding. However, the scarcity of land in many rice-growing areas of south-east Asia prevents the wide application of the method. Another difficulty is the greater distance to be covered by farmers going to and from their fields.

Experimental tests carried out mainly in Japan have shown that transplanted rice seedlings will grow and even yield 50% more crops by the intermittent irrigation method. Therefore, when water sources other than rainfall are available in sufficient quantity to permit periodic watering, the introduction of intermittent irrigation for rice cultivation could be a positive approach to malaria control in usually highly endemic regions (see Chapter IV, section 3.6).

Rice cultivation, with periodic but short intervals of flooding and drying, would not be more hazardous than the cultivation of other plants similar in height and leaf size and shape; the restriction on its cultivation near human communities would no longer be necessary.

5. Individual protection

Several measures of protection against biting mosquitos have been in use for many years with varying degrees of effectiveness. Some of them are accessible to most people living in rural areas.

Bed nets provide a material barrier against the attacks of night-biting mosquitos and some other insects. They have been widely used for centuries and, when properly made and used, have a definite effect in preventing disease transmission and annoyance by mosquitos. However, the day-biting habits of some mosquito species, inadequate maintenance of the nets, or simply

lack of care are factors that reduce their value.

The fabric of the cloth should be white, so that mosquitos resting on it can be seen, and strong enough to stand hard and long usage; cotton and synthetic textiles are widely used. The weaving should be fine so that the holes are small enough to prevent the passage of mosquitos but allow the greatest possible ventilation. A spacing of threads of 1.0-1.8 mm has proved to give adequate protection without undue hindrance to the passage of air.

The usual shape of the net is either conical (inverted funnel), wedge-like (camping tent), or prismatic (box with vertical walls). The box-like net provides, with approximately the same amount of material, a larger and more regular inside space than the other shapes. The vertical walls permit fuller use of the bed surface; this is an important advantage over the cone and wedge (tent-shaped) nets.

The lower edges can be weighted by tying beads, pebbles or other small heavy objects to assure the continuous contact of the net with the mattress or can be tucked under the mattress. Before sleeping, the inside should be inspected for any mosquitos present. Bed nets may be impregnated with pesticides or mosquito repellents. Bed nets with a mesh as wide as 6 mm or over six times greater than usually recommended, when saturated with repellent, can deter mosquitos for about a week. This would considerably increase the air circulation.

Clothing when sufficiently thick, or loose from the body, is an obstacle to mosquito biting. It has been an established practice and an army regulation to change the day clothes at sunset into long sleeves and trousers so that the legs and arms are not exposed to mosquito biting. Dark clothing renders the wearer more exposed to attack by mosquitos.

Insect repellents should fulfil certain conditions such as safety to the user, efficacy against mosquito species of the area, stability, and lack of unpleasant odour and staining properties. Recent research has resulted in repellents of more lasting effect than those used in the past, such as citronella. In the USA alone, 7000 synthetic organic chemicals were being tested at one time. The mixture of compounds has produced repellents several times more effective than citronella. At present, dimethylphthalate and diethyltoluamide are most commonly used.

In the application of repellents to the skin it is important that all the exposed parts should be treated thoroughly and liberally because mosquitos will soon find the small areas that are not covered by the repellent or were only lightly treated. Care should be taken to avoid application near the eyes as it may produce temporary but intense irritation. For protection against malaria mosquitos, the repellents should be applied especially at dusk and dawn which is when the anophelines are most frequently active. Mosquitos of other genera may be active at different hours of the day.

As mosquitos can pierce ordinary clothing, there is greater protection when the clothing is also treated with repellents. Aerosol dispensers or ordinary hand sprayers are most practical for such application of repellents. Impregnation of clothing with repellent can be done at the time of washing; a final rinse in a solution or emulsion (containing 10-20% of the repellent) will give good protection for the normal period between washings.

6. Zooprophylaxis

Zooprophylaxis involves the use of wild or domestic animals, which are not the reservoir hosts of a given disease, to divert the blood-seeking mosquito vectors from the human hosts of that disease. Zooprophylaxis has long been recognized as an important factor in reducing the endemicity of malaria in certain parts of the world. It may also be effective against other diseases, such as various viral diseases transmitted by mosquitos. It is most applicable where the use of cattle or other livestock fits into the local agricultural economy.

Since man is the only important vertebrate reservoir of malaria, zooprophylaxis is doubly

effective as a control measure: (a) diversion of infected mosquitos to other animals decreases the transmission rates to humans; and (b) feeding of mosquitos on "dead-end" hosts prevents the amplification of the pathogen in the reservoir host (man).

Both anopheline and culicine mosquitos show wide variations in the selectivity of their blood-feeding patterns. Some species, such as An. darlingi and An. sundaicus, are strongly anthropophilic — showing a high preference for feeding on man. In contrast, some species such as An. annularis and An. sinensis, are strongly zoophilic — showing preference for cattle or other non-human hosts. Other mosquitos, such as the An. maculipennis complex and Culex quinquefasciatus (= Cx. pipiens fatigans) exhibit facultative feeding patterns and feed readily on man as well as other vertebrate hosts. Some zoophilic mosquitos, such as An. pharoensis and Aedes vexans, show a high preference for domestic mammalian hosts; others, such as Culiseta melanura and Cx. pipiens, may show a high preference for avian hosts (ornithophilic).

Some mosquito species show high blood-feeding selectivity within vertebrate classes. For example, it has been shown that Cx. tarsalis may show a high preference for columbiform birds over other avian hosts; and Cx. quinquefasciatus may show a high preference for dogs over other domestic mammals.

It should be emphasized that host availability and behaviour, composition of species, and other ecologic factors govern the selectivity of mosquito blood-feeding patterns. Thus, a predominance of feeding upon one or more species should not be interpreted as a "deliberate preference" by the blood-seeking mosquito; however, for convenience we refer to selectivity in the blood-feeding patterns of mosquitos as "host preference". The forage ratio, which simply compares the percentage of feeding upon a particular host with its percentage composition of the total available hosts, has been used to measure the degree of host preference or selectivity.^a

Theoretically, zooprophylaxis would be most effective for mosquito species which have zoophilic or facultative blood-feeding patterns. The zoophilic habits of An. sinensis minimize its importance as a malaria vector in Asia and the western Pacific; and the heterophilic habits of Cx. tarsalis, which feeds on a wide variety of wild and domestic birds and mammals, is probably an important factor in the low endemicity of western equine and St. Louis encephalitis in the western United States.

In general, mosquitos are rarely obligate feeders upon a single host species. Even highly zoophilic species of Anopheles will feed upon man if their preferred host is not available. Thus, the availability of alternative hosts probably has an important influence on the endemicity of mosquito-borne diseases in many parts of the world.

Horses, cattle, sheep, and other domestic animals offer the best possibility for the application of zooprophylaxis as an environmental technique. For example, the importance of An. maculatus as a malaria vector in Malaysia and other tropical countries is believed to be inversely correlated with the abundance of cattle in the area. The same is believed to be true with regard to Cx. tarsalis as a vector of western equine and St. Louis encephalitis in rural areas of the western United States. The replacement of domestic beasts of burden by farm tractors has been believed to be a factor in increasing malaria transmission rates in some areas of South America where An. darlingi is a primary vector of malaria. It is interesting to speculate whether the abundance of dogs and the high preference of Cx. quinquefasciatus for canine blood in some urban areas of the tropics may not decrease the risk of human infection with filariasis.

^a Hess, A.D. et al. The use of the forage ratio technique in mosquito host preference studies. Mosquito news, 28:386-389 (1968).

In considering the application of zooprophylaxis for the control of mosquito-borne diseases, it is important to distinguish between reservoir hosts and dead-end hosts. For example, in rural areas where western equine encephalitis is endemic, hundreds of house sparrows nesting in the trees and outbuildings around farmhouses may divert many blood-seeking Cx tarsalis mosquitos from humans; however, since the house sparrows serve as intermediate reservoir hosts for virus amplification, the end result is an increase rather than a decrease in the amount of virus transmission to humans. On the other hand, cattle are dead-end hosts which do not serve as sources of virus infection for vector mosquitos; therefore, the diversion of blood-feeding mosquitos from humans to cows both decreases the amount of virus transmission to humans and prevents the amplification of the reservoir of virus. In contrast to cows, horses are apparent hosts and subject to clinical disease in the same way as humans. They must, therefore, be immunized against viral encephalitis if they are to play a role in zooprophylaxis.

In many situations, mosquito vectors produced in rural habitats invade adjacent villages in search of blood meals and transmit disease to the human population. This is true for various Anopheles vectors of malaria as well as culicines, such as Cx tarsalis. For example, in Indonesia, An. aconitus breeding in ricefields invades nearby villages and transmits malaria. In such situations, a zooprophylactic technique might be used involving the establishment, around the villages, of interceptor zones populated with cattle or other domestic animals. In the USSR, the health administration advises on the location of cattlesheds and houses in relation to mosquito breeding sites. It is generally recommended that, wherever possible, stables should be arranged as a continuous row along the periphery of the settlement. Distance between stables and houses should vary from 250 to 300 m. Zooprophylaxis would not, of course, be practicable unless the raising of cattle or other livestock were compatible with local agricultural practices and economy. Neither would it be effective if the mosquito flight patterns were appetential (in search of a blood meal), or if the mosquito species exhibited migratory flight patterns (e.g., Ae. sollicitans). It would be less effective if the mosquitos concerned were daybiters and the agricultural fields were located outside interceptor zones within mosquito infested areas.

Studies on the blood-feeding habits of mosquitos are being carried out in many areas of the world, and increased emphasis is being given to determining their relative preferences for man and other vertebrates. These studies will provide valuable information for the extended use of the method in the context of environmental management techniques.

7. Basic sanitary measures

The lack of basic sanitary installations and services or, when available, their defective design and construction or their improper use and maintenance can produce situations that increase man/mosquito contact. Although the mosquito habitats that result from inadequate sanitation are often small in extent individually, they can be so numerous and so close to human dwellings that they may have a greater disease transmission potential than larger but fewer and more distant ones. Some of the smaller habitats may even go undetected and thus escape monitoring and control.

Population growth in many cities in developing countries is so rapid that public utilities and services soon become inadequate and remain so indefinitely. Among these utilities, water supply suffers the most. The water is insufficient, the system pressure is low, and the service is unreliable with frequent breakdowns and leakages. People store water in their houses as a safeguard against a water failure; underground cisterns, roof tanks, water jars, and other vessels are used for this purpose. To increase the supply, rain-water may be collected and unused wells reopened. In rural areas, except where piped water supply and house connexions are available, the household storage of water is almost universal. All these reservoirs and containers, usually left unprotected and uncovered, may become suitable habitats for mosquitos such as the anopheline malaria vectors dthali, stephensi, claviger and varuna. The best permanent solution to this problem would be to improve the water supply; a temporary measure is to prevent mosquito access to these water containers by providing them

with proper covers or screens. A plastic floating mesh screen has been proposed for the old 50-gallon oil drums commonly used as water containers and promises to be effective and acceptable to the population.

The problem of small water collections exists in both urban and rural areas. Water pools are formed in ground excavations and depressions, in holes in streets and yards, etc., and are due to domestic wastewater, water through spillage or leakage from individual or community water supply systems or rain-water. This subject is dealt with in subchapter IIIE, section 3.

Many mosquitos, particularly some Aedes and Culex species which are vectors of arbovirus diseases and filariasis, can breed in man-made containers and other scrap materials, such as metal, carton, glass, plastic, etc., which (when abandoned on the ground) collect and hold rain-water. Larvae of these vectors have been found in sardine tins, car tyres, broken bottles, rubber boots, etc. In urban areas, only an efficient service of refuse collection and disposal, combined with public education and participation, can reduce the tremendous number of these latent and active sources of mosquito production. Refuse disposal can be done by burial, incineration, composting, etc. Buried waste should be covered and compacted (see subchapter IIIF).

As certain mosquito vectors of arbovirus and filarial infections (such as Culex pipiens and other Culex species) can breed in contaminated water, pit latrines, cesspools, sewers and even sewage treatment plants may provide breeding sites. Cesspools should always be kept covered and the sewage flow should be rapid enough to prevent oviposition. The problem of vector mosquito breeding in sewage treatment plants or in pit latrines penetrating into ground water may have to be overcome by chemical control methods.

It is therefore clear that the introduction of efficient, basic sanitary installations and services will be directly beneficial to the control of many mosquito-borne diseases, mainly through the reduction and elimination of mosquito sources.

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CHAPTER VI

PLANNING ENVIRONMENTAL MANAGEMENT FOR MOSQUITO CONTROL

CONTENTS

	<u>Page</u>
1. General principles	165
2. The planning of integrated control	166
3. Problem definition and priority rating	167
4. Delimitation of operational areas or selection of project sites	168
5. Feasibility studies	168
6. Selection of methods of control: the comprehensive approach	169
7. Vector-borne disease control programmes	169
8. Major land and water resource development projects	171
9. Control at community level with local participation	172
10. Evaluation	172
Further reading list	173

1. General principles

The techniques and methodologies described in preceding chapters are generally applicable (a) in planning programmes specifically and primarily for mosquito control, (b) in planning mosquito control as an integrated part of development projects, and (c) in recognizing and evaluating mosquito control benefits derived from development and community improvement projects.

There are considerable differences in planning environmental management for mosquito control programmes currently in operation and for new programmes. A prerequisite for both is the existence or establishment of mechanisms of coordination and institutional arrangements to ensure that the programme is consistent with other public needs and priorities. Traditionally, health ministries have played a leading role in the establishment and operation of public health mosquito control programmes and in efforts to have the mosquito control aspects considered when planning the development projects.

From examples cited in the foregoing chapters it is clear that a variety of environmental management techniques are being used singly or in combination in many existing mosquito control programmes. Present programmes are the result of gradual developments over several decades, and the tendency is towards integrated control programmes including environmental management methods, biological agents, and insecticides. For control programmes which still rely heavily upon insecticides, a shift towards greater reliance on environmental management may become necessary in the future owing to problems of vector resistance. The need for

greater programme effectiveness and reduced long-term costs may also be reasons for considering a shift to source reduction measures even though major capital expenditures may sometimes be involved initially. The economic feasibility of such a shift is established by comparing the estimated annual costs over the expected life of the source reduction measures, including amortization and maintenance, with the expected savings in expenditure for insecticides and in the cost of their application. Mosquito control projects (such as drainage, filling, diking, and dewatering) may provide opportunities for land reclamation and development benefits which may reduce incremental costs allocated to mosquito control.

In the planning of new mosquito control programmes, two requirements must in general be met: that of dealing with existing problems resulting from natural or man-made vector sources, and that of tackling both the existing and potential vector problems connected with the construction of a new water resource. The latter are dealt with in more detail below.

No two dam (and reservoir) projects are exactly alike. Each project has its own characteristics determined by the physiography of the site, its location, design features of the structure, and operating schedules to serve the purposes for which it is constructed. For any specific project the potential mosquito control problem is determined by the climate, the size and topography of the reservoir area, the condition of the area to be flooded with regard to drainage and vegetation, and the expected water level schedules to be followed (operating rule curves) to meet project requirements. If due attention is given to mosquito control in the earliest stages of project planning, it is possible through design, proper preimpoundage preparation of the area to be flooded (see subchapter IIIA), and judicious planning of reservoir operating schedules (see Chapter IV, section 1.3) to mitigate the potential problems and reduce or possibly eliminate the need for special postimpoundage mosquito control operations, such as larvicide.

Excessive mosquito populations associated with irrigation systems are most often caused by faulty engineering design, and incorrect irrigation, drainage, and management practices. The mosquito sources are often associated with both the engineering and the agricultural aspects of irrigation and are thus amenable to correction or prevention, through proper planning. Irrigation systems and practices designed to attain maximum efficiency and to minimize water wastage tend also to avoid creating conditions favourable to mosquito propagation. However, some current design features and practices are not best suited for mosquito control. For example, in large irrigation projects, the slopes of the main canals are usually reduced so that larger land areas can be irrigated. The lessened flow velocity and the consequent vegetation growth are favourable to mosquito production. Similarly, prolonged flooding of rice fields is still a common practice although intermittent irrigation has shown its effectiveness for mosquito control with little or no effects on the crop.

For mosquito control in new communities, the principal considerations are site selection, disposal of waste water, surface drainage, disposal or proper handling of water-holding containers, and housing standards that reduce man/mosquito contact (see Chapter V).

The wide-scale application of environmental management for mosquito control can be included in primary health care programmes and will contribute to the goal of health for all by the year 2000. Simple environmental management measures taken by communities can assist in reducing mosquito vector habitats. Individuals can contribute to mosquito control and general community development, but special education is frequently needed. Individuals can limit the number of breeding places on their own premises by minor drainage and removal of water-holding containers. They can also provide personal protection for themselves and their families by the use of mosquito nets, space sprays, etc. (see Chapter V).

2. The planning of integrated control

The principles enunciated in a policy statement adopted by the American Mosquito Control Association in 1979 are indicative of modern approaches to mosquito control. Although stated for general mosquito control purposes, the principles reproduced below also apply to vector

control programmes.

The American Mosquito Control Association advocates management of mosquito populations, when and where necessary, by means of integrated programmes designed to benefit or to have minimal adverse effects on people, wildlife, and the environment. This integrated pest management policy recognizes that mosquito populations cannot always be eliminated but often must be suppressed to tolerable levels for the well-being of humans, domestic animals, and wildlife, and that selection of scientifically sound suppression methods must be based on consideration of what is ecologically and economically in the long-term best interest of mankind. The following principles are advocated.

- (1) Mosquito control measures should be undertaken only when there is adequate justification, based upon surveillance data.
- (2) Integrated mosquito management programmes should be tailored to the needs and requirements of the local situation. The combination of methods for mosquito control should be chosen after careful consideration of the efficacy, ecological effects, and costs versus benefits of the various options, including public education, legal action, natural and biological control, elimination of breeding sources, and insecticide applications.
- (3) Mosquito breeding sources, whether natural or created by human activity, should be altered in such a manner as to cause the least undesirable impact on the environment.
- (4) Insecticides and application methods should be used in the most efficient and least hazardous manner, in accordance with all applicable laws and regulations and available scientific data. The registered label requirements for insecticides should be followed. When choices are available among effective insecticides, those offering the least hazard to non-target organisms should be used. Insecticides should be chosen and used in a manner that will minimize the development of resistance in the mosquito populations.
- (5) Personnel involved in mosquito management programmes should be properly trained and supervised, and certified in accordance with relevant laws and regulations, and should keep current with improvements in management techniques through continuing education and/or training programmes.

For vector control programmes, principle (1) may be broadened to include epidemiological data. Furthermore, in the assessment of the effects of measures to control the vectors of one disease, the benefits from the complete or partial control of a number of other vector-borne diseases should be included.

A considerable body of knowledge about many mosquito species is needed for planning effective control programmes. Information on some important species was presented in Chapter I, and Tables are included in Annex 1. Additional information on local species needs to be collected, compiled and analysed.

3. Problem definition and priority rating

Before a vector control programme is planned, some information will usually be available on disease prevalence and on the ecology of the vectors. Data may also exist which will enable the relative public health and socioeconomic importance of the disease to be assessed. To establish the priority of the vector control programme relative to other health activities of the area, data on other major communicable diseases of the area are needed. Such information will also be useful at later stages of programme development for the selection of control methods that may also alleviate other health problems. Where data are incomplete, it may be necessary to carry out small-scale epidemiological surveys.

Information on the prevalence and sources of mosquito vectors in the area is analysed and major sources are identified. These may be natural breeding areas, man-made irrigation schemes, rice cultivation systems, or artificial lakes. Potential future sources of vectors, such as prospective water resource development projects in the area, should also be considered. An evaluation should be made of any past programmes or current activities for control of mosquito-borne diseases in the area. Particular attention should be directed to the effectiveness of the control methods employed, the problems encountered, and programme administration and costs.

To obtain an overall view of the problem, information is needed on the demographic, physiographic, climatological, topographical and geographical features of the area, population distribution, water resource development projects, and related engineering data such as streamflow, drainage, and water control operations.

The findings of the problem definition study should be reviewed with the governmental agencies of the area responsible for public health, agriculture, public works, industrial development, conservation, water resources, tourism, etc. The purpose is to obtain the views of these agencies as to the potential benefits or impacts of a vector control programme for their programmes. The review also serves to identify opportunities for joint planning and possibly joint funding of projects, in which mosquito control is included with other objectives such as flood control, hydroelectric power generation, navigation, irrigation, drainage, land reclamation and development, or fish and wildlife enhancement.

4. Delimitation of operational areas or selection of project sites

In large-scale vector control projects, it is to be expected that the areas for which a control programme is being considered will include different epidemiological and ecological conditions with resulting differences in disease transmission potential and in the appropriate control measures. Delimited sectors of the designated control area can be used for conducting feasibility studies and preliminary detailed planning of vector control programmes to provide the basis of a total programme plan of operations.

The geographical location of a water resource development project is determined primarily by the purpose of the project, the area to be served, and technical requirements for construction and operation of the works. In considering alternative schemes for site development, however, the assessment of the relative difficulties and costs of vector control may be an important factor, and it is for this reason that data must be collected at an early stage.

Vector-borne disease control should also be an important factor in the selection of sites for housing the construction workers and for resettling the populations that have been displaced by the project.

5. Feasibility studies

Prior to the project planning stage, feasibility studies are conducted to determine whether the control objectives can be attained with available methods and resources, taking into consideration the local technical, operational, administrative and socioeconomic conditions.

The relationships of population groups to vector sources have a great bearing on cost-effective vector control strategies. For example, a strategy including a large-scale programme of larval control would be more likely to be cost-effective in densely populated urban areas than in rural areas. As indicated above, these relationships provide a sound basis for subdividing the control area into sectors to be used for feasibility studies.

The technical feasibility of environmental management methods will depend on the efficacy of available control measures in the proposed control area. In some cases, small-scale field trials of the control measures may be needed to confirm their efficacy and technical

feasibility. If the feasibility of available control methods seems to be questionable, new methodologies and equipment may have to be developed and assessed in a field operation before a soundly based control programme can be initiated.

In the selection of methods to be incorporated in an integrated control programme, operational feasibility as well as technical feasibility must be considered. This requires study of the practicability of applying various control methods under the local geographical, physical, social and climatic conditions. This study should take account of communications, housing, agricultural practices, human habits and customs, water resources and existing public health programmes and organization.

The results of the sector studies can be combined to provide preliminary estimates of the resources required and the costs for implementing the total programme. Usually, only direct costs are included in the sector cost estimates. For the total programme costs, technical planning, management and administrative costs need to be added. Provision should also be made for special investigations and field trials for programme improvement and continuing evaluation of programme effectiveness.

A feasibility study should also take into account the rules and procedures on the allocation of funds and accounting of expenditure, the recruitment and training of personnel, procurement of supplies and materials, maintenance and repairs of transport, legislation and legal support, as well as any other administrative and managerial matters related to the programme.

Only control measures which pass the tests of both technical and operational feasibility should be considered for application in the control programme. Comparative cost estimates will indicate the cost-effectiveness of alternative control strategies and, in turn, indicate the methods of control for each sector that would be most cost-effective. In cases where direct benefits to other interests are to be realized, these should be taken into account.

6. Selection of methods of control: the comprehensive approach

Following the feasibility studies, and if it is decided to proceed, detailed surveys are usually needed. These will include preliminary engineering studies if major projects are concerned. The project should be developed within the total health and socioeconomic context of the area to ensure that other diseases are taken into account in the selection of control measures. This comprehensive approach involves the careful selection of a combination of methods on the basis of their efficacy, feasibility of application, costs, suitability to local conditions and acceptability to the population. Within the wide scope of water resources development, where many different and possibly conflicting interests may be involved, a coordinated approach is essential in all phases of development.

7. Vector-borne disease control programmes

Although no two situations involving the development of a vector control programme are identical, some generalizations may be made. In urban areas characterized by high population density, source reduction measures should be emphasized. Where the mosquito control operations extend beyond the geographical jurisdiction of a municipality or where overlapping jurisdictions are involved, the formation of mosquito control districts may be required but these should be consistent with the pattern of basic health services.

The situation in suburban areas of towns is sometimes more serious. Mosquito production is usually more intense because of the presence of more surface water for mosquito breeding, and if the resulting health problems are severe, other measures of control may have to be combined with environmental management operations and the provision of basic sanitary measures.

In these and in rural areas, the control strategy should consist of a combination of measures with more emphasis at first on chemical control to bring about a rapid decline in

mosquito density and disease transmission. As environmental management operations are developed and strengthened, the application of pesticides can be reduced and gradually replaced by non-chemical measures.

In rural areas and arid zones, excessive mosquito populations are frequently due to man-made habitats. Vector control efforts have to be directed to measures which involve conservation and optimum use of the limited water supply. In tropical zones with an oversupply of water, drainage and land reclamation may be emphasized as methods for source reduction. However, adequate mosquito control cannot usually be achieved through environmental management alone, since it is difficult to provide sufficient coverage of existing and potential breeding places. Integrated strategies and selection of courses of action similar to those recommended above for urban areas should be applicable to most rural situations.

Organization and management of operations. Large-scale projects for environmental management require a high degree of technical direction, efficiency in operational activities, and sound management. The director and key staff should be technically qualified and have basic management skills for administering a large organization of people. The technical staff should understand the technical operations of public works, such as irrigation and drainage, and water supply and drainage systems, in order to deal effectively with technical personnel responsible for these works.

Organization patterns must of necessity be tailored to individual situations and placement of the project in the governmental structure.

Training of staff. Basic to all environmental management for mosquito control is a nucleus of trained personnel including an entomologist with broad training in aquatic ecology and a knowledge of control methods, and an operations director who could be an environmental or public health engineer trained in vector control. In some situations all of the functions may have to be performed by only one engineer who will then be responsible for training ancillary staff such as laboratory and entomology technicians in the application of their skills to environmental control, and for organizing training programmes for field personnel.

Pilot operations. As mentioned above, pilot operations may be needed to determine the technical feasibility of a proposed control method. These trials provide excellent training opportunities. When integrated control programmes are being planned, adequate allowance should be made for extended pilot operations.

Engineering surveys and design studies. Some source reduction projects may involve small or simple drainage or water control operations which the average workman can perform using a simple hand level or no instrument at all (see Chapters II and VII). Such operations might include side drainage to primary drainage channels and drainage of shallow depressions in filled areas. Most source reduction projects will, however, require trained engineers to conduct instrument field surveys, make designs, and estimate the cost of alternative schemes. In projects primarily for mosquito control, the role of the vector control specialist is to identify the areas to be considered, develop performance specifications, arrange for engineering surveys, design and cost studies, and arrange for final designs and construction. In multipurpose projects, his role is usually limited to indicating how specific features of the project might be designed to optimize mosquito control benefits and to evaluating the effectiveness of alternative schemes to that end.

It is unlikely that a vector control organization will have staff qualified to conduct engineering and design studies. Contracts may be made with professional engineering companies, or the engineering staff of departments of public works or other appropriate governmental agencies can be used.

Impact on the environment. Environmental management measures may produce a significant impact on the environment. In some countries, environmental impact studies may require extensive surveys, considerable financial resources, specialized manpower, and legal and

administrative support. In other countries, the impact study may consist in gathering available knowledge from specialists and the public at large; their contributions may provide practical assistance in planning the project. Where such procedures are not available, a simple matrix of the type discussed in Chapter II, section 4, and in Annex 3 can be helpful in the assessment of environmental impacts, at least during the initial stages of project development.

8. Major land and water resource development projects

There is much documented information on mosquito control efforts related to major water resource development projects such as dams, reservoirs, and irrigation schemes, but less attention has been given to mosquito control problems associated with other types of projects such as channel dredging, land drainage, land reclamation, road construction, and water management for rice cultivation.

As stated above, the basic approach should be to incorporate mosquito control features in project design and operation. At the same time, a close cooperative working relationship must be established with the health authorities in all phases of project development, and the project authorities and management must accept responsibility for ensuring that the control of mosquitos of public health importance is not weakened but is rather improved.

During the planning phase, the health component of the project should include: (a) compiling data on the health status of the area and other related subjects such as vector densities; (b) undertaking surveys to supplement the data, bringing them up to date, or extending them in greater detail; and (c) identifying present health problems and predicting possible future repercussions of the project. Feasibility studies, cost-effective analyses, etc., should take the health component into account.

During the design phase, the health component should include: (a) establishing criteria for the minimization of health hazards, and (b) advising designers on the incorporation of these criteria in the design of structures and other works and in the planning and design of operations.

During the construction phase, the following health safeguards will need to be established: (a) protection against disease, and medical care of the construction labour force, including control of local vectors; (b) advice on adequate housing, sanitation facilities, and services for the labour force and resettled inhabitants; (c) inspection to ensure that construction is in compliance with approved designs as related to vector control features; and (d) organization of programmes for health education and community participation.

At the beginning of the operations phase, the health organization should be ready to undertake such activities as: (a) surveillance, screening and treatment of infected persons, health training of irrigation and agricultural personnel, and public health education and development of community participation; (b) continued monitoring of the works for their effect on vector densities; and (c) evaluation of vector density and disease change, the effectiveness of vector control and sanitation, etc., and further steps that are required for good environmental management.

Effective coordination calls for the establishment of coordinating boards and committees within the framework of the project at various administrative levels. The boards and committees should be a part of the project organization and should have carefully defined duties and areas of responsibility. They should have the full support of the project management, reinforced (if need be) by appropriate legislation. Meetings of the boards and committees should be regular.

The potential adverse health effects of water resources development projects are of vital concern to public health authorities. It is therefore essential that the Ministry of Health should have adequate powers and resources to control the vectors of public health importance

in water resources projects. It is desirable that official authorizations for the planning, design, construction, operation and maintenance of major water resources development projects should define the responsibility of the project management to comply with the vector control requirements.

9. Control at community level with local participation

At the community level, the available resources, equipment and technical skills are frequently limited but this does not necessarily preclude the successful application of simple environmental management measures for vector control through cooperative local participation. For such participation to be effective, the planning of basic sanitation measures (including vector control) must include technologies which are conducive to labour-intensiveness and decentralization, and which meet the needs of a large percentage of the people in the community.

Appropriate technology approaches to community vector control and sanitation are just as applicable to the unplanned settlements of migrant workers, who are frequently brought together for the construction of water resources development projects, as they are to established communities. In the former case, however, the need is greater and the task is frequently more difficult and has less probability of success.

Simple technology that is available and easily adaptable to many community situations can deal with, for example, the improvement of surface drainage, the filling in of small land depressions, the removal of containers that provide larval habitats, encouragement of the use of bed nets and repellents, and the promotion of better house construction (see Chapter V).

In the established communities, vector control activities should be integrated with primary health care and carried out by community workers. Technical assistance for planning and supervision and certain incentives may need to be provided by vector control staff.

The selection and establishment of priorities for health and development projects are the prerogatives of the community leaders, but health workers can assist by identifying health problems, suggesting priorities, and proposing corrective measures by community action and alternative approaches with the estimated manpower and equipment requirements. Health workers will need to continue to assist in developing specific work plans, in training personnel, and advising on the allocation of funds and equipment where necessary. The success of individual projects will in part depend on the training of the community workers responsible for carrying them out. Health personnel should also assume major responsibility in providing training to local health workers for the extended health education of the public.

10. Evaluation

Evaluation is the measurement of the progress achieved towards the planned objectives. It consists in regularly collecting data on various aspects of programme development and comparing them with the set targets. Evaluation needs to be continuous and should lead to the design and introduction of corrective measures to overcome deficiencies, and perhaps also to a revision of goals and targets. For environmental management projects, evaluation should cover the epidemiological aspects, environmental impact, and the economic aspects.

Operational evaluation assesses the progress of administrative, technical and financial operations. It is carried out to maintain high operational standards.

Epidemiological evaluation measures the impact of the measures against the vectors and disease. It is carried out by comparison of data collected through a regular reporting system or through epidemiological surveys. The results may indicate the need for a change in strategy if they fall short of the targets.

The environmental impact assessment will keep watch on the physical modification of the

environment and its effects on the biota (see section 7 above, Chapter II (section 4), and Annex 3).

In the economic studies, usually the benefits other than vector control are assessed and, if possible, quantified. These may include assessment of the additional water and land for agriculture and urbanization, improvements in environmental quality, and overall improvement in socioeconomic conditions.

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CHAPTER VII

PRACTICAL GUIDELINES FOR THE VECTOR CONTROL WORKER

CONTENTS

	<u>Page</u>
1. Introduction	176
2. Procedures for implementing simple environmental management works	176
2.1 Review and analysis of the existing data and reports	177
2.2 Preliminary reconnaissance and problem identification	177
2.3 Surveying	178
2.4 Selection of methods	178
2.5 Detailed design and construction	182
2.6 Operation and maintenance of constructed works	182
2.7 Monitoring and follow-up	182
3. Organization of work	182
3.1 The executing body	182
3.2 Reorientation of the vector control service	183
3.2.1 Training of staff	183
3.2.2 Pilot operations	183
3.2.3 Organizational reorientation	183
3.3 Application of environmental management measures in new programmes	184
3.4 Community participation	184
3.5 Primary health care	185
4. Design and construction hints	185
4.1 Calculation of earthwork for filling	185
4.1.1 Determination of the area of the top surface of a land depression	186
4.1.1.1 Marking out right angles on the ground	189
4.1.2 Determination of the mean depth of a land depression	189
4.2 Velocity of flow in open channels	191

	<u>Page</u>
4.3 Drainage ditches	195
4.3.1 General hints	195
4.3.2 Design of drainage ditches: some examples	198
4.3.3 Setting an alignment between two points which are not within sight	204
4.4 Improvement of shorelines	205
4.5 Some basic facts about concrete	205
5. Plane surveying for environmental management works for vector control	206
5.1 Definitions	207
5.1.1 Plane surveying and geodetic surveying	207
5.1.2 Measurement of lengths and direction	207
5.1.3 Measurement of angles	208
5.1.4 Measurement of elevation	208
5.2 Levelling	209
5.2.1 Levelling procedure	210
5.2.2 Profile levelling	210
5.2.3 Establishing grades	213
5.2.4 Cross-section levelling	213
5.2.5 Levelling for construction	213
5.2.6 Substitute tools for levelling	215
5.3 Plane-table surveying	219
5.3.1 Introduction	219
5.3.2 The instrument	219
5.3.3 Methods of surveying with the plane-table	220
5.3.3.1 Setting up the table	220
5.3.3.2 Traversing	221
5.3.3.3 Plotting the detail	222
5.3.3.4 Measuring elevations	223
5.3.4 Field party	224
5.3.4.1 Personnel	224
5.3.4.2 Equipment	224
Further reading list	225

1. Introduction

The vector control service will usually be responsible for implementing small and simple environmental management measures as part of the disease control programme. Its staff should be capable of planning, designing and carrying out such measures, aimed principally at eliminating vector breeding sites. Public health inspectors or sanitarians attached to the vector control service may be required to direct the work in the field and organize the unskilled workers in its execution. They should be particularly prepared for such field activities.

Much of the information in this Manual is addressed both to vector control workers and to engineers engaged in water resources and other development projects, but the practical guidelines in this chapter are concerned only with works and operations which vector control workers may be required to carry out by themselves. These works, even though they seem small and simple, may be as effective in controlling mosquito production as larger and more impressive undertakings.

In cases where the guidelines prove insufficient, vector control field staff should always feel free to refer matters to and request help from their supervisors as well as from specialized professionals or agencies (where available) at the field level. The vector control service should also establish and maintain close collaboration with the departments responsible for water resources development, and request technical support as and when required. Community participation and cooperation with primary health care services should also be sought.

2. Procedures for implementing simple environmental management works

For the implementation of environmental management works, the general sequence of activities is usually as follows:

- (a) Review and analysis of existing data and reports on vectors, diseases, and their control.
- (b) Preliminary reconnaissance, to collect additional general information and to identify the mosquito problem.
- (c) Land surveying, including topographical surveying, as required, to provide detailed geographical information on the area concerned for use in the planning and design process.
- (d) Selection of environmental management measures to be applied, based on data collected through (a), (b) and (c).
- (e) Detailed design of the environmental management works required, including construction plans and cost estimates.
- (f) Construction.
- (g) Operation and maintenance of the constructed works.
- (h) Continued evaluation of the impacts on vector or disease incidence and the introduction of corrective measures.

The various activities listed above are discussed, step by step, in the subsequent sections. It may be noted that not all the steps and activities are needed for every job and several of them can be omitted in the case of small operations.

2.1 Review and analysis of existing data and reports

Collect existing data and reports on vectors, diseases and their control and analyse them with a view to identifying the general vector and disease problem in the area as well as the information gaps.

2.2 Preliminary reconnaissance and problem identification

Step 1. Visit the area concerned and collect information on the following:

- the prevalence of malaria and other vector-borne diseases, if not already available;
- the number in the population, and location of their permanent and temporary habitation;
- whether the agricultural fields and crops are irrigated or rain-fed;
- the climate, rainfall (magnitude and seasonal distribution), temperatures, groundwater table, and soil characteristics;
- the location and extent of each existing (and potential) mosquito source; in the case of water collections, determine from where the water comes (surface runoff or groundwater sources), the water level or depth, and the duration and season of water accumulation; vegetation growth; and the mosquito or disease potential (what environmental management measures, singly or in combination, would provide a solution?);
- if drainage is considered as a possible solution, determine any possible outlet, its distance from (and its elevation in relation to) the lowest point of each water collection, and its capacity to carry away the additional flow (would partial drainage provide a solution?);
- if filling is considered as a possible solution, determine any possible sources of filling material and their locations relative to the water collections (would margin improvement by deepening and filling, plus introduction of larvivorous fish, provide a solution?);
- the use being made of the water collections (if any), and whether their elimination (either by drainage or filling) is acceptable to the local population;
- if flushing is considered as a possible solution in the case of a ditch or stream, determine the quantity of water available for flushing, and possible locations for the storage structure;
- if other manipulative measures (such as salinity changes) are being considered, determine the possibilities for such measures and the requirements for their implementation;
- the availability of labour in the area, and the prospects of participation by the local communities in the envisaged work for environmental modification.

Step 2. Based on the findings of the reconnaissance, in particular the number and size of the existing mosquito sources to be dealt with, the vector control officer at the central or district level should:

- determine (as far as possible) the magnitude and the complexity of the environmental management work involved; and
- determine whether or not the job can be adequately handled by the vector control staff.

Step 3. If the job is too large or complex for the vector control staff, refer it to the appropriate department for action. Follow-up by the vector control service will be required.

If the job can be handled by the vector control staff or by the community under their guidance, proceed with land surveying.

2.3 Surveying

Step 1. Obtain and study the available maps of the area concerned.

Step 2. Determine what additional surveying is required, if any. For simple fillings or drainage there will be no need for surveying, in most instances. For larger jobs that can be handled by vector control staff, plane-table surveying, contour levelling and traverse levelling would probably be sufficient in most situations. Basic surveying methods are described in section 5 below.

Step 3. Organize and carry out the surveying.

2.4 Selection of methods

Environmental management measures that have proved useful for vector control have been given in Chapter II and are also mentioned in Annex 2. These methods have been described in detail in Chapters III and IV; however, in these two chapters, in particular in the former, the emphasis has been largely given to the application of environmental management measures in water resources development projects for the prevention, reduction or control of vector breeding. The selection and application of these measures purely for vector control, either singly or in appropriate combinations, obviously depends on the individual situation; however, consideration should be given to as many alternative solutions as possible so that a suitable and effective method of control is found.

Most water accumulations can be eliminated or controlled in several ways; an analysis should be made to determine whether the particular water body should be drained (or filled) and reclaimed for agricultural or other productive use, whether it should be converted to a reservoir or lagoon with improved margins by deepening and filling, or whether the water should be conserved by diversion to a reservoir at a suitable point. In some instances, a slight lowering of a swamp's water level can draw off water from the shallow margins and stop mosquito breeding while the deeper areas can be stocked with larvivorous fish. In other situations, raising the water level by installing a low dam at the downstream end may flood the flat shallow margins and strand the mosquito larvae or destroy them by wave action and predators. The possibility of water level fluctuation should also be investigated. Where very high flood water conditions occur occasionally, the excess flood flow should be by-passed through its natural route to protect drains (see subchapter IIIC, section 4). In coastal situations, the manipulation of water salinity in the swamp may provide the desired control. Therefore, complete draining or filling of a water body may not be the best solution and should not invariably be resorted to. The more economical and simpler environmental management works should be given first consideration.

In principle, the selection of a measure (or a combination of measures) for application in a given situation depends on: (a) the cost/effectiveness of the measure as compared with alternative measures; (b) the operational and financial feasibility of the measure; and (c) other considerations, including acceptability to the population, side benefits, and the extent and importance of other vector and disease control measures applied. The following basic steps should be followed in this selection process:

Step 1. Based on the findings of the preliminary review and reconnaissance and the details of the land survey, list the various environmental management measures that alone (or combined) could provide effective mosquito control.

Step 2. Study the operational feasibility of each alternative.

Step 3. Estimate the cost of each alternative.

Step 4. Study the financial feasibility of each alternative.

Step 5. Assess the effectiveness of each alternative.

Step 6. Compare the cost/effectiveness of each alternative.

Step 7. Examine other advantages (including side benefits) and the disadvantages of each alternative.

Step 8. Make the selection.

A village pond that breeds mosquitos can be used as an example to illustrate how this procedure may be applied in selecting an environmental management measure for mosquito control. The various steps are shown below:

Step 1. Possible solutions:^a drainage, filling, margin improvement by deepening and filling plus introduction of larvivorous fish, mosquito proofing, and larvicing. Larvicing is not an environmental management measure but is included in this example so that its recurring cost may be compared with the costs of long-term measures.

Step 2. From the survey we know that (a) the pond serves no useful purpose to the local inhabitants, (b) there is a stream near the village where the pond water can be drained, and (c) there is also a high spot in the village from which earth can be removed for filling the pond. Larvivorous fish are available. The houses (about 50) in the village are so constructed that they can readily be screened. Larvicides, sprayers, and labourers are also available for carrying out larvicing. Therefore, all the five alternatives are technically feasible. Note that if no suitable outlet is available in the vicinity of the village (or the pond), the alternative of surface drainage would have to be discarded because it is not operationally feasible.

Step 3. Costs for the five alternatives are estimated as follows:^b

US\$

(a) Drainage:

Digging the drainage ditch	5200
Maintenance (no operation cost)	100/year

(b) Filling:

Initial cost	6400
Maintenance (no operation cost)	negligible

^a There could be other solutions, but the example given is limited to five alternatives in order not to complicate the case.

^b These costs are fictitious and are given only as an example.

US\$

(c) Deepening and filling, plus larvivorous fish:

Cost for deepening and filling	3500
Introduction of fish	negligible
Maintenance, including vegetation removal	260/year

(d) Mosquito proofing:

Screening the doors and windows	10 000
Maintenance and replacement	1000/year

(e) Larviciding:

Initial cost	negligible
Recurrent cost of larvicides, operations, and replacement of equipment	1200/year

Step 4. Financial feasibility. An amount of \$6500 has been budgeted for community improvement and can be used for drainage and filling purposes. There is also a budget item of \$1500 per year for mosquito control. Therefore all alternatives other than mosquito proofing are financially feasible. The financing of mosquito proofing would depend on the willingness and the financial means of the home owners, which would require further investigation.

Step 5. The relative effectiveness of the five alternatives in vector control, as far as this source (the pond) is concerned, may be rated as follows:

Drainage: 95%; Filling: 100%; Deepening and filling, plus larvivorous fish: 90%;
Mosquito proofing: 80%; Larviciding: 90%.

Step 6. Comparison of cost/effectiveness.

Cost comparison of the alternatives can be made on the basis of either the "total annual costs" or the "capitalized costs", both involving compound interest computations. In the example given here, the comparison is made on the basis of the total annual costs (AC), which can be expressed as:

$$AC = Cr + \frac{Cr}{(1 + r)^n - 1} + OM$$

where C is the capital cost, r the interest rate, n the number of years during which the investment will be recovered, and OM the operation and maintenance cost.

The cost comparison of the five alternatives is shown in the Table overleaf, assuming n = 20 years and r = 10%. The amortization cost is calculated from the formula

$$\frac{Cr}{(1 + r)^n - 1}$$

	<u>Drainage</u>	<u>Filling</u>	<u>larvivorous fish</u>	<u>Mosquito proofing</u>	<u>Cut & fill plus larvivorous fish</u>	<u>Larviciding</u>
Capital cost (\$)	5200	6400	3500	10 000		-
Interest on investment (Cr) (\$)	520	640	350	1000		-
Amortization $\left(\frac{Cr}{(1 + r)^n - 1} \right) (\$)$	91	112	61	175		-
O & M cost (\$)	100	-	260	1000	1200	
Total annual cost (AC) (\$)	711	752	671	2175	1200	
Effectiveness (%)	95%	100%	90%	80%	90%	
Cost/effectiveness $\left(\frac{AC}{\% \text{ effectiveness}} \right) (\$)$	748	752	746	2719	1333	

It is seen from the above comparison that drainage, filling, and cut and filling plus larvivorous fish have about the same cost/effectiveness; the other two alternatives can be eliminated on account of cost/effectiveness considerations alone.

Step 7. Other considerations.

The three promising alternatives can now be compared with respect to other considerations as follows:

	<u>Drainage</u>	<u>Filling</u>	<u>Cut & fill plus larvivorous fish</u>
Annual costs/% effectiveness	\$748	\$752	\$746
Possible future use of the pond area	not much use is foreseen	can be made a public park, a recreation area, or possibly used for housing	raising fish, recreation
Acceptance by the population	OK	Preferred	Preferred

Step 8. Selection of an alternative.

In the light of the above comparison, probably "cut and fill plus larvivorous fish", the environmental management alternative with the least initial cost, will be selected as the method to eliminate the mosquito problem. "Filling" will probably be the second choice in view of its other advantages, though it is slightly less cost/effective than drainage. This is of course only a simplified example; real field situations are much more complicated. The possibility of community participation and many other factors that also need to be taken into consideration in the selection are discussed in Chapter VI.

2.5 Detailed design and construction

Once the appropriate environmental modification measure has been selected, the next activity is to plan the detailed design of the work to be carried out. However, for very small jobs (such as simple drainage or filling) a detailed design would probably not be needed, and they can be successfully carried out with proper organization. Organization, supervision and technical support are particularly important when the work is to be performed by the communities themselves or by voluntary labourers provided by the communities. For larger jobs it may be necessary to calculate the amount of earthwork involved or to design a drain, ditch, etc., before construction starts. Some hints on the design and construction of the medium-sized environmental modification works are given in section 4 below. Large drainage schemes would require complicated hydrological studies, hydraulic and structural design of canals and ancillary structures, detailed cost estimates, and comprehensive construction specifications and plans. Large-scale land filling and grading projects usually aim at balanced cut and fill, involving laborious calculations. The services of engineers and perhaps power equipment will be needed for such jobs, and no attempt is made to cover these subjects in this Manual.

2.6 Operation and maintenance of constructed works

For large-scale water resources development projects, the operational procedures and schedules of the schemes should be well thought out and clearly drawn up during the planning and design stages. In the preparation of the operational procedures and schedules, due consideration should be given to the vector control requirements and, in particular, the environmental manipulative measures. The importance of maintenance cannot be over-emphasized. Suitable maintenance programmes should also be charted out during the planning and design stages, and the required finances should be provided for in the project's recurrent budget.

Small drainage and filling jobs would require very little maintenance.

2.7 Monitoring and follow-up

The impact of the control measures on the vector and disease situation should be continuously monitored. Data such as vector densities (adult and larval) and disease incidences, as selected by the entomologist and the epidemiologist, may be used as bases for evaluation. Corrective measures should be introduced if the evaluation results indicate that the measures applied are not providing the desired control.

3. Organization of work

3.1 The executing body

Small and simple environmental management jobs can be undertaken by the vector control staff as part of the control programme. Community participation must be secured because it ensures acceptability and maintenance of the works, once completed, and also helps to reduce costs. Some of these jobs can be carried out by the involved communities themselves, with technical and material support from the vector control service as and when required.

The vector control service may be able to handle certain types of larger-scale work, if it has an adequate qualified staff and if support is available (when required) from other departments such as public works, irrigation and drainage, etc. For really large-scale and complex jobs, departments other than vector control where a large and experienced engineering staff exists would be suitable to take up the executing responsibility. The services of consulting engineering firms and construction contractors are also resorted to when the size and nature of the job so justify.

It is seen that the vector control service is directly responsible only for the implementation of small to medium-scale environmental management jobs. However, for the success of vector control efforts, it should play a very active promotional and coordinative role in the

water resources development projects that are undertaken by other departments in order to ensure that appropriate environmental management measures for vector control are incorporated in these projects. It must be borne in mind that often large-scale environmental management measures can hardly be justified on vector control benefits alone. Therefore every attempt should be made to link such measures with an economic activity (e.g., drainage or filling for land reclamation, ponding for fish culture, etc.), so that these measures can be justified on economic grounds in addition to the vector control benefits, and can be financed by funds other than the vector control allocations.

3.2 Reorientation of the vector control service

At present, environmental management measures are applied only on a very limited scale in a few operating vector control programmes. Therefore, the experience, expertise, services and facilities available with existing programmes in the environmental management field are also very limited. The introduction and expansion of these measures should thus be in stages in order to prevent any undue interruption in the normal running of the programme.

The most practical approach is to begin with the training of staff and the organization of pilot operations to assess the operational feasibility, cost/effectiveness and other implications of applying the various environmental management measures as part of the programme. At a later stage, the vector control service must be suitably reoriented towards the integrated use of these measures.

3.2.1 Training of staff

The staff of vector control services need to be conversant with the various environmental management methods and with the techniques and equipment required to apply them so that they will be able to plan operations incorporating these methods in an integrated control strategy. Senior officials of national services who will be potential trainers in their respective countries should benefit from international seminars or workshops on environmental management for vector control or on integrated vector control. After such training, these persons should organize national courses for their own staff. This manual could be used as an important reference document in both the international and the national training courses.

3.2.2 Pilot operations

Pilot operations should investigate the feasibility and implications of various environmental management methods and their cost/effectiveness under different field conditions, and develop appropriate operational procedures and practices for an integrated field application of all methods.

In the selection of sites for pilot operations, priority should be given to areas where environmental management measures are most needed (e.g., areas with vector resistance problems, development projects, and urban situations), and arid areas where these measures are most cost/effective. The operations should be extensive enough and cover as large an area as necessary to allow conclusive assessment of the results. They should be properly planned and implemented; the relevant procedures, as suggested in section 2 of this Chapter, may be found useful.

A duration of 2-3 years may be necessary for pilot operations, but some preliminary results may be available for application even after the first year. Pilot areas can also be used for the practical training of staff.

3.2.3 Organizational reorientation

The vector control service needs to be appropriately reorganized in relation to its new activities, notably (a) the planning and application of environmental management measures as an integral component of the control strategy, and (b) the maintenance of closer coordination and collaboration with other health sectors and with agriculture, irrigation, public works

and other development projects. It may be necessary to create a new division or section within the service to deal with this new area of activities, and most of the retrained staff can then be absorbed in this division or section which should be headed, ideally, by a sanitary engineer.

The reorientation should be very carefully planned and should be implemented in consonance with the gradual change of emphasis towards the environmental management measures that have longer-term effects. The reorganization of the service should also take place in the provincial and field levels.

While building up its technical capability, the vector control service should also gradually build up its stock of equipment for carrying out simple environmental management works and for their maintenance.

3.3 Application of environmental management measures in new programmes

In new vector control programmes, environmental management should be taken into consideration from the beginning of surveys and planning and at the time of formulating an integrated control strategy. During reconnaissance surveys, attention should be given to the identification of suitable areas for environmental management operations. Data on topography, hydrology and geology should be collected along with epidemiological and entomological information, to allow the planning of environmental management measures as part of the control strategy (see section 2 of this Chapter). The vector control service to be established should include a suitably staffed unit responsible for environmental management.

Normally, vector-borne disease control programmes aim at an initial sharp reduction in disease prevalence and transmission. This can be achieved through the application of insecticides, or through chemotherapy, both of which have the advantage of producing quick results. It is therefore reasonable that reliance should be placed on such measures during the early stages of a control programme, and the environmental management methods should gradually be allowed to take over the consolidation and maintenance of the gains in the following years. It must be noted that the environmental modification measures usually take time to be implemented and need specialized expertise. It may be necessary to introduce these measures at the beginning of the programme, so that they will become effective in due time.

3.4 Community participation

It is recognized that in the implementation and maintenance of environmental management works for vector control much can be achieved through community participation. Efforts to enlist the cooperation and participation of the people are unlikely to be effective, however, unless the proposed actions are closely related to their real needs and concerns.

The needs of a community usually cover several sectors, including health, and the priorities vary from one community to another. It has been observed that the general population is appreciative of the integrated approach of primary health care, in which vector-borne disease control is an essential element in combination with other health and social services.

The following steps may be suggested for promoting community participation:

- (a) Carry out surveys (i) to study the attitude of the population towards health and disease in general and towards vector-borne disease control in particular, (ii) to obtain information on the existing community infrastructure and community leaders, and (iii) to identify the priority health needs of the community.
- (b) Design the technical programme to meet the real needs and concerns of the people, and translate it into terms which make sense and are within the capability of the population for implementation.

- (c) Jointly with the community leaders, prepare a practical plan of action, specifying in detail what is to be done by the population, and in what way it is to be done, taking into account the existing community infrastructure.
- (d) Work out a plan for the provision of incentives, if desirable and feasible.
- (e) Jointly with the community leaders, educate the population by informing them of the plan, convincing them of its relevance to their needs and ensuring their active participation.
- (f) Help the community to organize and implement the planned activities, and follow up and maintain the spirit of community participation.

It should be borne in mind that a programme involving community participation can succeed only if the population concerned are sufficiently well prepared so that they will demand action, they are ready to take part in or even carry out the work by themselves, and they are willing to preserve the gains achieved through the action taken by proper maintenance.

3.5 Primary health care^a

Primary health care (PHC) is a system designed to attack community health problems through promotive, preventive, curative and rehabilitative actions, as required. The PHC approach forms an integral part of the country's health care system (of which it is the key-stone), and of the overall social and economic development of the nation and the community.

Vector-borne disease control is one of the functions of primary health care and environmental management measures for vector control are practicable at community level by the community members. The vector control programme should therefore take all possible steps to ensure the integration in primary health care activities of environmental management measures for vector control.

4. Design and construction hints

4.1 Calculation of earthwork for filling

For very small filling jobs, it may not be necessary to estimate the amount of earthwork involved. For medium-sized jobs, an approximate estimation of the quantity of the filling material required is useful. For large-scale jobs, greater accuracy and more extensive land measurement will be required.

In theory, the following formula gives the volume of fill:

$$V = Adm$$

where V is the volume of the depression to be filled (m^3),

A is the surface area of the pond (m^2), and

dm is the mean depth of the pond (m).

To apply the above formula, the surface area and the mean depth of the depression will need to be known. As all natural land depressions are of irregular shapes and depths, the difficulty in determining these two measurements, in particular the latter, to a high degree of accuracy is obvious. Methods for obtaining approximate values for small to medium-sized jobs are described in sections 4.1.1 and 4.1.2 below.

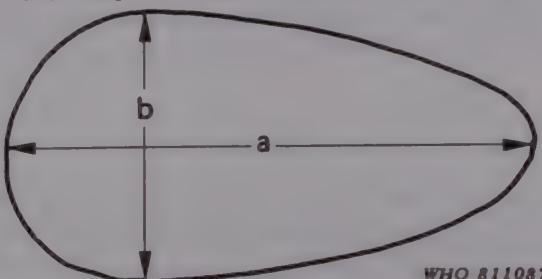
^a See also: Alma-Ata 1978. Primary health care. Geneva, World Health Organization, 1978 ("Health for All" Series, No. 1).

The actual volume of earth required for filling the land depression will be more than that calculated since allowance must be made for subsidence, shrinkage and compaction. It may be assumed that the quantity of material actually required will vary from 1.1 times the calculated volume (for coarse-textured sandy soil) to 1.4 times (for fine-textured clay-loam).

4.1.1 Determination of the area of the top surface of a land depression

(a) In the case of a small, rounded or egg-shaped pond, two field measurements will be sufficient for determining its area with adequate accuracy: one on its major axis or the longest possible measure, a , and the second at right angles at the widest section, b (see Fig. VII-1). The pond should be small, say 20-25 m in length, so that it can be traversed by a measuring tape without excessive sagging.

The surface area (A) may be calculated with the following formula: $A = \frac{1}{4} \pi ab$



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Fig. VII-1. Measurements for calculating the surface area of a small pond. The area will be close to $\frac{1}{4} \pi ab$.

(b) In the case of an irregular pond, the following are the steps to take the field measurements and to calculate the surface area:

Field measurements

Step 1. Mark a rectangle that encloses the pond which is considered as an irregular polygon.

The marking of the rectangle on the ground is usually made by driving stakes at the corners and, if necessary, at intermediate points. A tightly stretched cord tied to the stakes forms the sides of the rectangle. Provided that the angles at the corners are right angles (90°) and the parallel sides are equal, the direction, location and length of the sides are arbitrary; in this way, the most convenient ground (flat and unobstructed) can be chosen for the rectangle.

Step 2. Measure the perpendicular distance (or the shortest distance) from each vertex (or corner) of the irregular polygon to the nearest side of the established rectangle. A simple method for marking out right angles is described in section 4.1.1.1 below.

All measurements are taken either along or at right angles to the sides of the rectangle. In most cases the two longer sides of the rectangle are used, but when distances from the pond periphery to these sides is too long, the two shorter sides can be used likewise. If the ground is thickly covered with vegetation, it should be cleared beforehand.

Step 3. Keep a record of the measurements, supplemented by a sketch.

Fig. VII-2 shows the measurements needed for plotting the outline of an irregular pond. From the vertices, or points where the perimeter changes direction abruptly (A, B, C, etc.), perpendiculars are marked out to the nearest side of the rectangle and their lengths are measured (a_2, b_2, c_2 , etc.). The distances between the perpendicular lines (a_1, b_1, c_1 , etc.) are measured at the same time. In practice it is easier, and the risk of error is less, if the measurements along the side of the rectangle are taken with the zero mark of the tape

fixed at the corner stake, so that the measured distances are a_1 , (a_1+b_1) , $(a_1+b_1+c_1)$, etc. These two sets of measurements form what is known in geometry as a system of rectangular coordinates, and they are used in plotting the outline of the pond on paper.

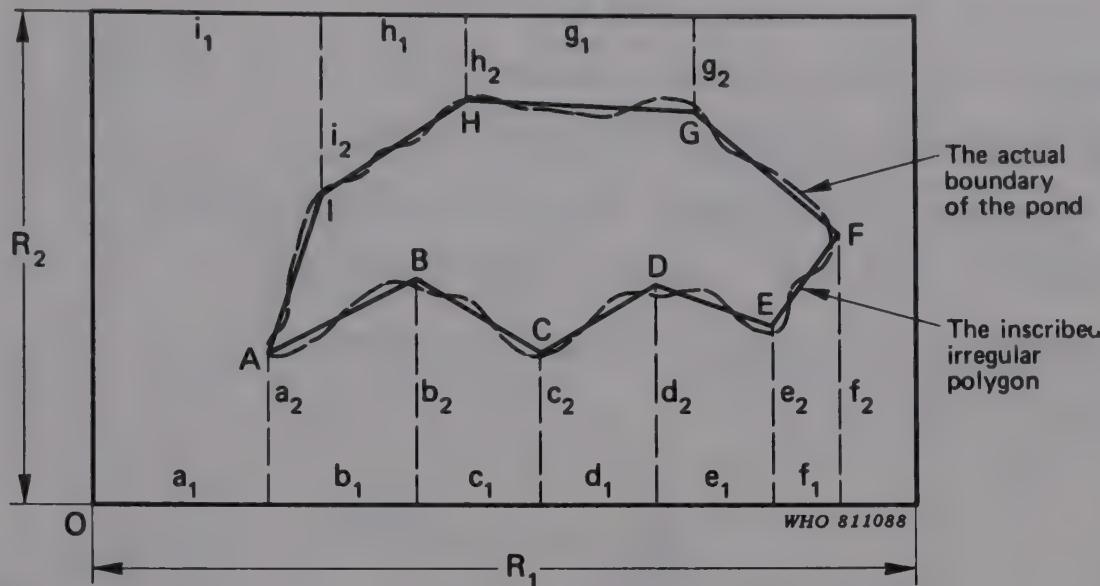


Fig. VII-2. Measurements needed for plotting the outline of an irregular pond.

The measurement of the perimeter of the pond from vertex to vertex (AB, BC, CD, etc.) will provide a means for checking the accuracy of the other measurements, when these are plotted on paper.

The measurements are usually taken with a steel or cloth measuring tape, 30 to 50 m long.

A pair of straight rods or staffs, about 2 m long with a pointed end, are used to align the intermediate points. These rods can also be used for reaching muddy edges if the end-ring of the tape can be hooked to a screw at the end of the rod. Light-weight pipes also make good measuring rods. Stakes used for marking the rectangular frame should be about 5 x 5 cm in cross-section, straight, and long enough to be easily visible; this is particularly necessary in ground that is covered with high grass.

Calculation of the surface area

Step 1. Plot to scale the outline of the pond on paper.

The drawing of the shape of the pond on paper is done by first plotting the coordinates of each point (or vertex) on a suitable scale with reference to two perpendicular lines or axes drawn on the paper. Then connect the adjacent points and the resulting polygon will represent the pond. The measured distances of the sides of the polygon (AB, BC, CD, etc.) can now be used to check the accuracy. Should any gross discrepancies be found, both the paper plotting and the field measurements should be reviewed in order to discover the mistakes.

Step 2. Calculate the area.

Once the perimeter of the pond is drawn on paper, it is possible to determine the area enclosed by the polygon in several ways. One method is to divide the polygon into triangles and to calculate the areas of the triangles by using an appropriate formula. An illustrative

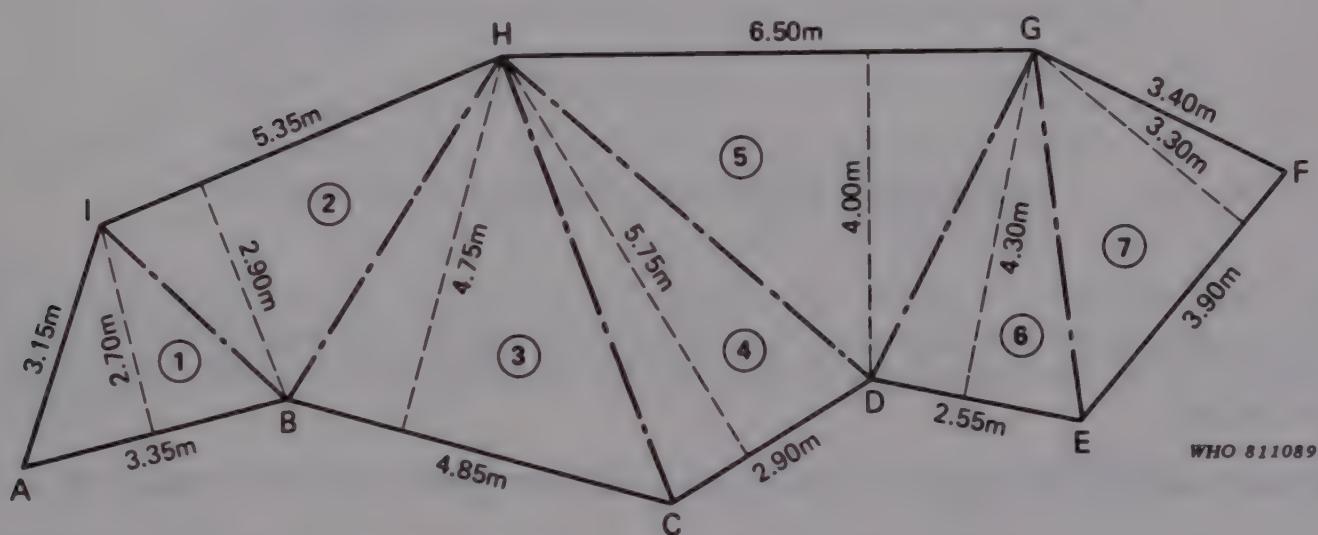
example of this method is given below. Descriptions of other methods^a may be found in text books on surveying.

Example: Calculate the area of the polygon as shown in Fig. VII-2 by dividing it into triangles.

- (1) Divide the polygon into triangles (see Fig. VII-3).
- (2) Using a side of the polygon as base, draw the height of each triangle.
- (3) Measure the heights of the triangles from the drawing.
- (4) Calculate the areas of the triangles using the following formula:^b

$$A = \frac{1}{2}bh, \text{ where } A \text{ is the area, } b \text{ the base, and } h \text{ the height.}$$

- (5) Add up the areas of the individual triangles to obtain the area of the polygon.



- Sides of polygon, actually measured in the field.
- - - Supplementary sides of triangles.
- - - Heights(h) of triangles, measured from drawing.

Area of a triangle $A = \frac{1}{2}bh$, where b is the base and h is the height.

A_1 = Area of Triangle (1); A_2 = Area of Triangle (2); etc.

$$\begin{aligned}
 A_1 &= \frac{1}{2} 3.35 \text{ m} \times 2.70 \text{ m} = 4.52 \text{ m}^2 & A_5 &= \frac{1}{2} 6.50 \text{ m} \times 4.00 \text{ m} = 13.00 \text{ m}^2 \\
 A_2 &= \frac{1}{2} 5.35 \text{ m} \times 2.90 \text{ m} = 7.76 \text{ m}^2 & A_6 &= \frac{1}{2} 2.55 \text{ m} \times 4.30 \text{ m} = 5.48 \text{ m}^2 \\
 A_3 &= \frac{1}{2} 4.85 \text{ m} \times 4.75 \text{ m} = 11.52 \text{ m}^2 & A_7 &= \frac{1}{2} 3.90 \text{ m} \times 3.30 \text{ m} = 6.44 \text{ m}^2 \\
 A_4 &= \frac{1}{2} 2.90 \text{ m} \times 5.75 \text{ m} = 8.34 \text{ m}^2 & A_1 + A_2 + A_3 + \dots + A_7 &= 57.06 \text{ m}^2
 \end{aligned}$$

$$\text{Area of the polygon} = A_1 + A_2 + \dots + A_7 = 57.06 \text{ m}^2$$

Fig. VII-3. Calculation of the area of an irregular polygon by dividing it into triangles.

^a Other methods include: (a) dividing the polygon into strips of equal width and calculating the area using either "the trapezoidal rule" or "Simpson's rule"; (b) calculating the area by using coordinates of the vertices; (c) measuring the area from the drawing using a planimeter.

^b Another formula for calculating the area of a triangle A is $A = \sqrt{s(s-a)(s-b)(s-c)}$ where a , b and c are the three sides of the triangle and $s = \frac{1}{2}(a+b+c)$.

4.1.1.1 Marking out right angles on the ground

To take field measurements for determining the surface area of a pond (see above), it may be necessary to set out a perpendicular to a line from a point outside it. Two simple means for achieving this are described here (see Fig. VII-4).

A cord is tied to form a loop of 3.6 m; three markers are fixed so as to divide the loop into three portions of 0.9 m, 1.2 m and 1.5 m which correspond to the two sides and hypotenuse of a right-angled triangle. The markers could be knots, coloured cotton or rings firmly secured; small rings have the advantage of producing sharp angles when pulled to stretch the cord. To set out a perpendicular to a line from a point outside it, a cord is tied to a peg at the point and stretched towards the line. One of the sides of the triangular loop is made to coincide with the cord from the outside point and this cord is swung sideways until the other side of the triangular loop coincides with the line.

Another method of marking out a perpendicular is to stretch a cord from the outside point and mark the two points where it intersects the line. The perpendicular will pass by the mid-point between the two marks on the line (see Fig. VII-4).

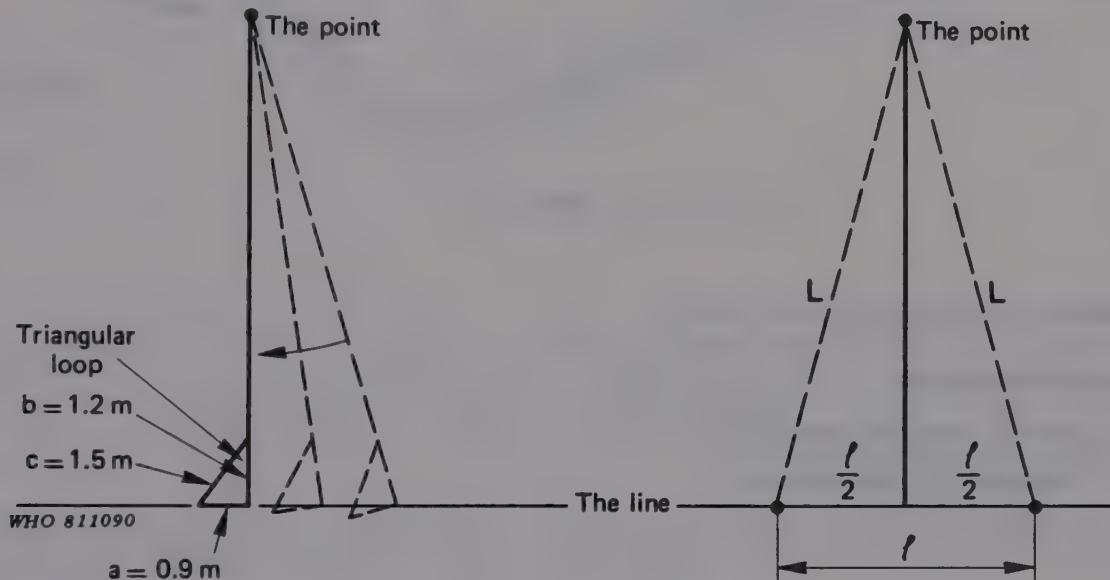
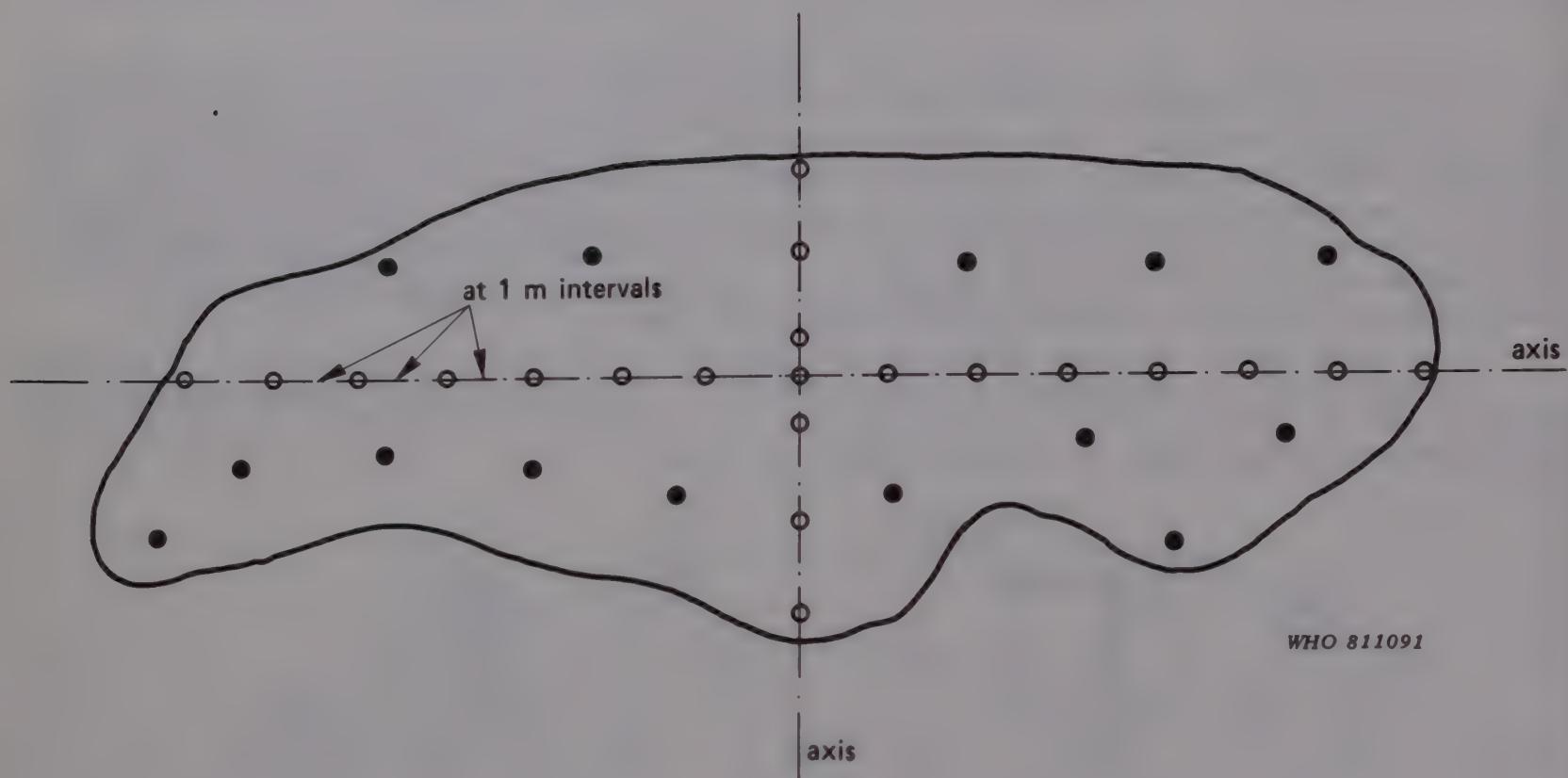


Fig. VII-4. Procedures for marking out a perpendicular to a line.

4.1.2 Determination of the mean depth of a land depression

Field measurement of the depths at different locations in the land depression is necessary in order to determine the mean depth. Given the irregularities of natural depressions, it is obviously difficult to obtain an accurate figure. In principle, the larger the number of field measurements, the greater the accuracy will be.

It is suggested that for the field measurement of the depths, two perpendicular axes should first be established, one in the direction of the length of the depression and the other in the direction of the width. Ideally, the axes should cross the deepest areas of the depression. The depths will be measured along the axes at suitable intervals, depending on the degree of accuracy required (see Fig. VII-5). Additional measurements may be made at random if desired.



- Depth measurements along long and short axes
- Depth measurements at random

$$\text{Mean depth} = \frac{\text{Sum of depth measurements}}{\text{Number of measurements}}$$

Fig. VII-5. Field measurements of depths of a land depression.

In case the land depression has distinct sections of different depths, the depression should be divided into shallow and deeper parts for the calculation of surface area, mean depth and volume. This is illustrated in Fig. VII-6.

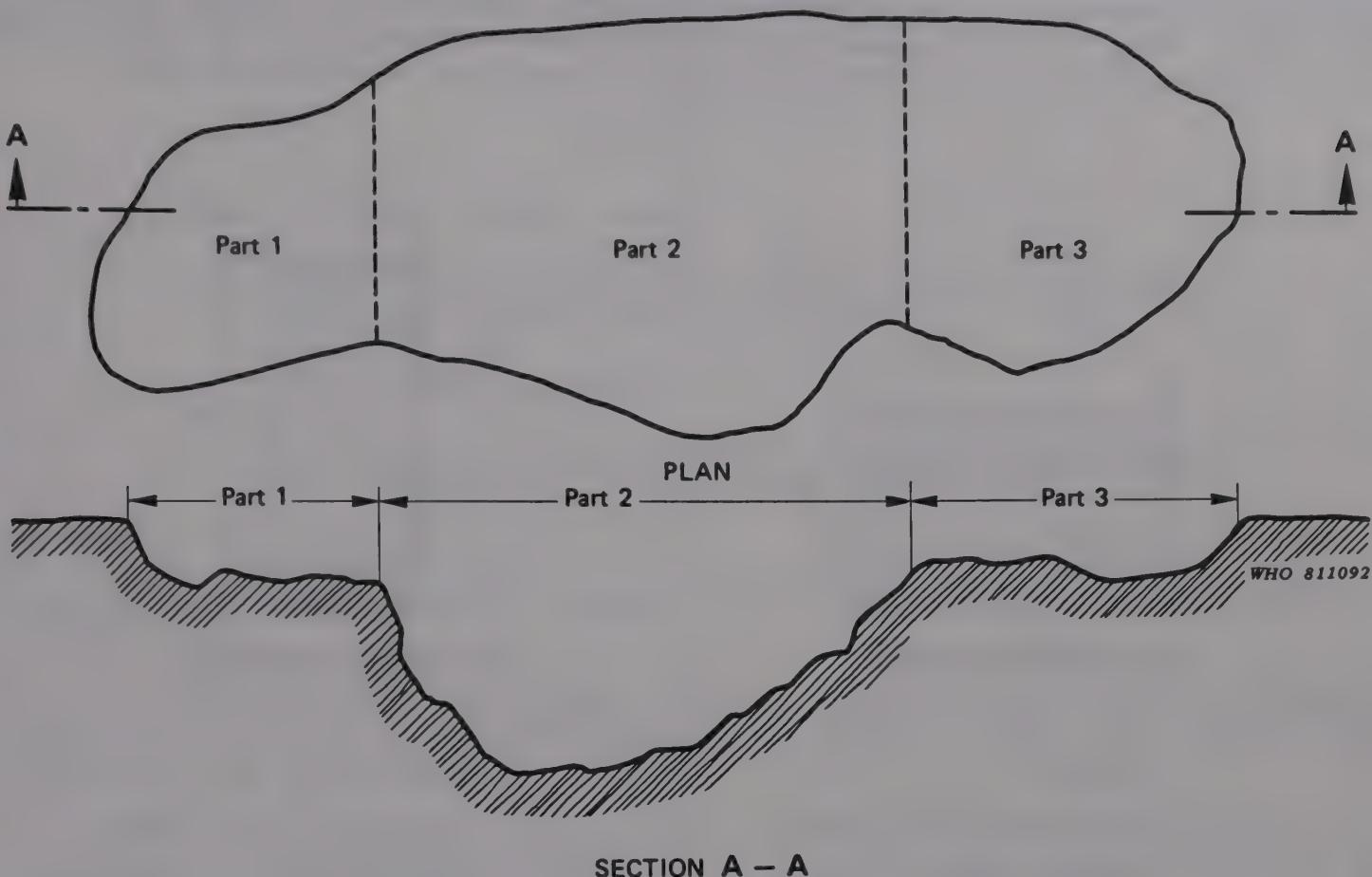


Fig. VII-6. A land depression having distinct sections of different depths should be divided into separate parts in the calculation of surface area, mean depth and volume.

If the depression is not filled with water, the depth can be determined by levelling (see section 5.2 below). In the case of a pond, sounding^a will be needed to determine the depths.

4.2 Velocity of flow in open channels

Perhaps the most frequent request put forward by health officials to engineers and designers of irrigation systems is to increase the water velocity in canals and drains. This matter is crucial as on it primarily depends whether the malaria mosquito can lay eggs or the schistosomiasis snail can settle and multiply.

The water velocity in open canals depends on three factors: the hydraulic gradient, the geometry of the cross-section, and the roughness (or smoothness) of the channel surface.

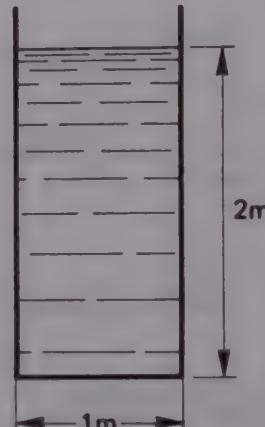
The hydraulic gradient (S) is the loss of energy per unit length as the water flows in open or closed conduits. In canals it corresponds to the slope of the surface of the moving water, which is roughly the same as the slope of the canal bed when measured between two distant points.

^a For sounding in a small pond, the water surface is used as a reference. A rope with knots to mark the metres and coloured graduations at 10 cm intervals can be used to measure the water depths at different points of the pond. The water depths must first be adjusted to the final ground level of filling to calculate the earthwork required.

The geometry of the cross-section is expressed by the hydraulic radius (R), also known as the hydraulic mean depth, which is the ratio of the cross-sectional area (A) to the wetted perimeter (W.P.). Fig. VII-7 illustrates how the hydraulic radius changes for canals of the same cross-sectional area but with different geometry (shape) of the cross-section.



RECTANGULAR SECTION



RECTANGULAR SECTION

$$A = 2 \text{ m}^2$$

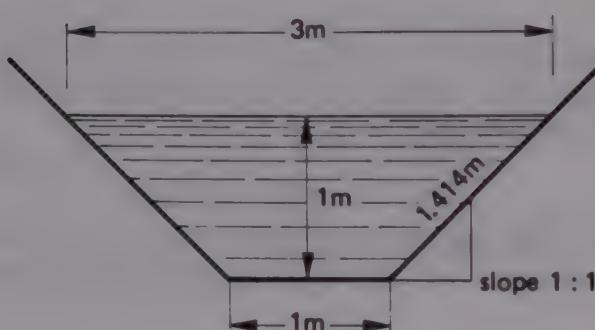
$$\text{W.P.} = 1 + 1 + 2 = 4 \text{ m}$$

$$R = \frac{2}{4} = 0.500 \text{ m}$$

$$A = 2 \text{ m}^2$$

$$\text{W.P.} = 2 + 2 + 1 = 5 \text{ m}$$

$$R = \frac{2}{5} = 0.400 \text{ m}$$



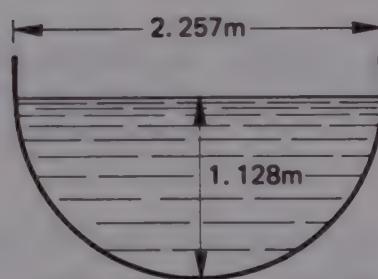
TRAPEZOIDAL SECTION

$$A = \frac{1 + 3}{2} = 2 \text{ m}^2$$

$$\text{W.P.} = 1.414 \times 2 + 1 = 3.828 \text{ m}$$

$$R = \frac{2}{3.828} = 0.522 \text{ m}$$

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SEMI-CIRCULAR SECTION

$$A = \pi \times 1.128^2 \div 2 = 2 \text{ m}^2$$

$$\text{W.P.} = \pi \times 1.128 = 3.544 \text{ m}$$

$$R = \frac{2}{3.544} = 0.564 \text{ m}$$

Fig. VII-7. Values of hydraulic radius for canals of the same cross-section but with different hydraulic shape.

The roughness of the channel surface influences water velocities because of the resistance it presents to the flow. It depends on the nature of the material that forms or lines the channel as well as the condition of the channel. It is usually expressed in terms of a coefficient, which is called the coefficient of roughness (n). Obviously an unlined earth canal has greater roughness, i.e., a higher n value, than a concrete-lined canal, especially when the former is infested with vegetation growth.

Several formulas have been devised to express the relationship between the velocity of flow in an open channel and the three influencing factors described above. The Manning formula is commonly used and is presented below for easy reference:

$$V = \frac{1}{n} \times R^{2/3} \times S^{1/2}$$

where V = mean velocity (m/sec)

R = hydraulic radius (m) = cross-sectional area of water prism divided by wetted perimeter

S = hydraulic gradient

n = coefficient of roughness; values of n for different channel linings are shown in Table VII-1.

Graphical solutions of Manning's formula can be obtained by the use of a nomograph as shown in Fig. VII-8.

Once the mean velocity (V) is obtained, the rate of discharge or the carrying capacity of the canal (Q in m^3/sec) can be calculated from the formula $Q = AV$, where A is the cross-sectional area of the canal in m^2 .

As can be seen from Manning's formula, there are three ways to increase the mean velocity in an open channel: by reducing the roughness, by increasing the hydraulic radius, or by increasing the hydraulic gradient.

As regards hydraulic radius, the most efficient of all possible hydraulic shapes of a canal section is a semicircle, open at the top and flowing full. The best polygonal section is one circumscribed about a semicircle; the greater the number of sides, the greater the efficiency. Hydraulic efficiency is of importance chiefly as a means of reducing the size and the cost of the waterway for a given carrying capacity on a given slope. However, this theoretical approach often conflicts with practical factors that have a greater influence on construction costs, notably the easiness and convenience of working.

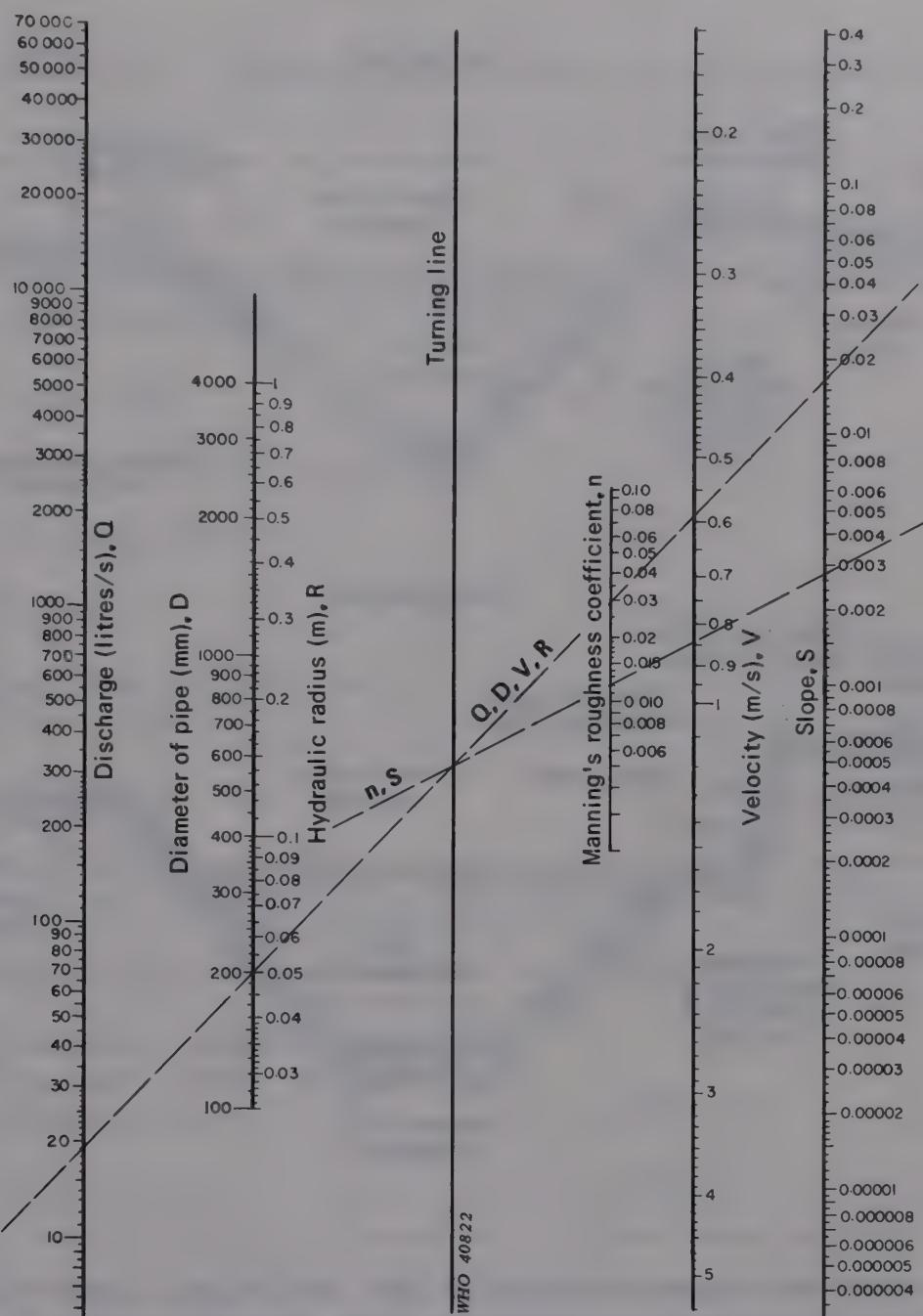
The hydraulic gradient of a canal depends on the topography of the land, and therefore its manipulation is subject to considerable practical limitations. First, many large irrigated plains are rather flat, thus offering little possibility for manoeuvring. Secondly, the design engineer is interested in keeping the water at the highest possible elevation so as to command the largest area for irrigation and therefore locates the canals along the highest terrain and gives them the minimum slope that is compatible with the prevention of silt deposition. It must also be noted that the velocity varies with the square root of the slope; this means that doubling the slope will only result in a 41% increase in velocity.

It is clear that the practical way to increase the flow velocity is to reduce the roughness of the canal surface. This can be readily achieved by canal lining. Lined canals will not only increase the velocity but will also tolerate a higher velocity. Canal lining has been dealt with in section 6 of subchapter IIIB.

Table VII-1. Manning's coefficient of roughness (n) for unlined and lined canals.

Surface conditions	Value of n	Surface conditions	Value of n
Unlined canals			
Smooth natural earth canals, free from weed growth, little curvature	0.020	Soil-CEMENT	0.015
Small canals in good condition	0.025	— well-finished	0.016
Earth canals with considerable aquatic weed growth	0.030-0.035	— rough	0.016
Earth canals with thick aquatic weed growth	0.040-0.050	CEMENT MORTAR (hand finished)	
Rock canals — main canals	0.030-0.035	— normal	0.013
— small canals	0.035-0.040	— maximum	0.015
— smooth and uniform	0.025-0.040	SHOT-RETE (Gumite)	
— jagged and irregular	0.035-0.050	— normal	0.017
		— maximum	0.018
			0.019
			0.023
Lined canals			
CEMENT CONCRETE		PRECAST CONCRETE BLOCKS (slabs)	0.015-0.017
— exceptionally good finish (rare)	0.011	PRECAST CONCRETE FLUMES	0.012-0.016
— very well-finished linings	0.013	BRICK	
— well-finished for straight canal reaches	0.013	brickwork in cement mortar	0.013-0.017
— worldwide adopted value for well-finished linings	0.014	— exposed brick surface (design figure)	0.0146
— worldwide adopted value for average finished linings	0.015	— exposed brick surface (actual measured value)	0.018
— widely adopted value for poor finish or for curved reaches (France)	0.017	STONEWORK	0.018-0.0225
— poorly finished, badly maintained canals	0.018	DRY RUBBLE MASONRY	0.023-0.035
ASPHALTIC CONCRETE		EXPOSED PREFABRICATED ASPHALT MATERIALS	0.015
— machine placed	0.014		
— smooth	0.014		
— rough	0.017		
BURIED MEMBRANE AND COMPACTED EARTH LINING			
— small canals	0.025		
— large canals	0.020-0.0225		

Fig. VII-8. Nomograph for the solution of the Manning formula (metric units)



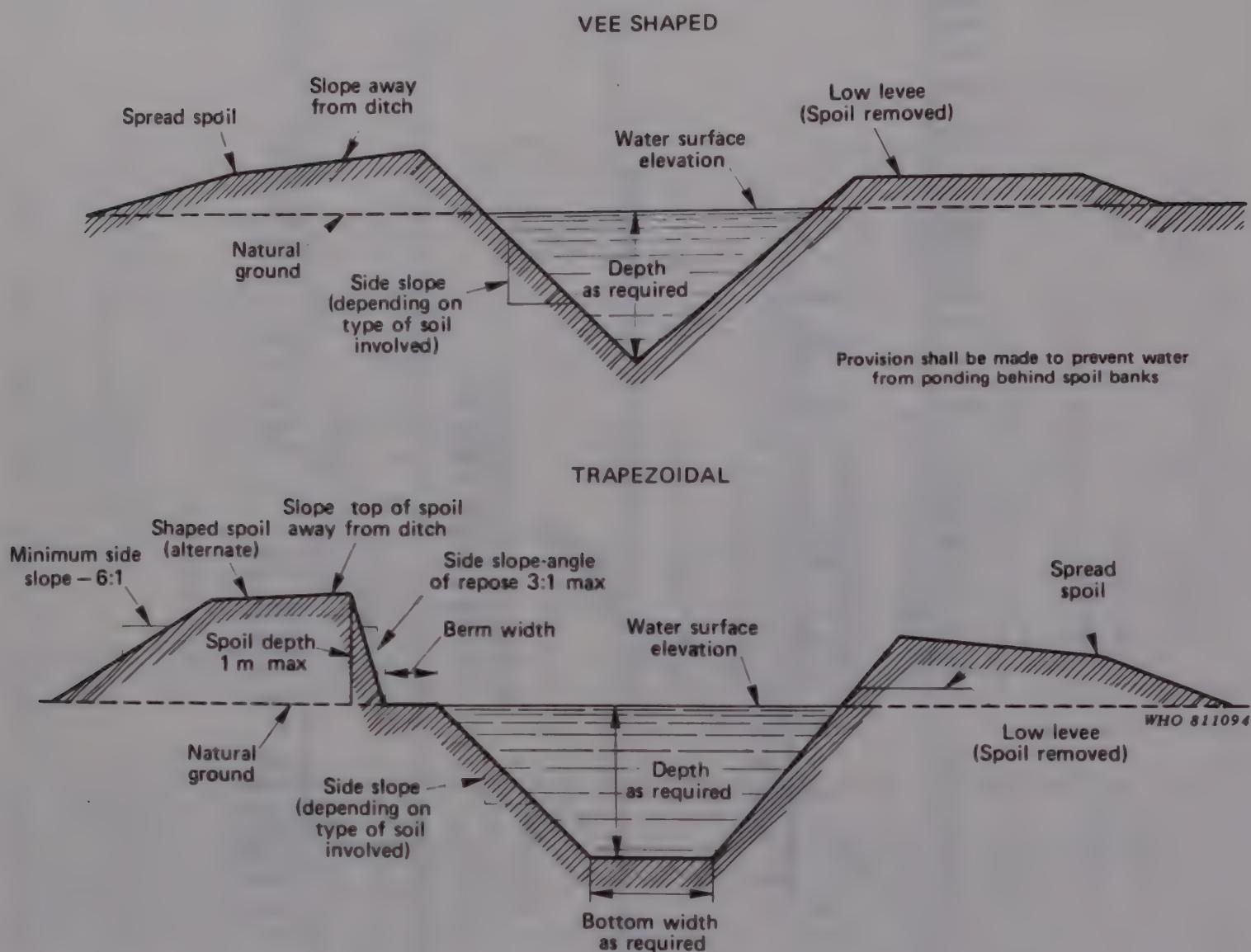
4.3 Drainage ditches

4.3.1 General hints

Ditches dug by hand up to 40-50 cm depth may be as narrow as 25-30 cm. However, should a greater depth be needed, the width of the ditch will also have to be increased. This increase is to provide sufficient shoulder room for the labourer, as he will have to stand on the bottom of the trench to work. A flat bed of 50 cm width may make it possible for digging to about 1 m depth. Thus, for small drainage jobs, the size of the ditch is determined more by the size of the digger than the carrying capacity required of the ditch.

In malaria control operations, it is frequently desirable to use a ditch with a narrow bottom width or a V cross-section, so that during low flow periods the flow will continue within the narrow cross-section without becoming a meandering channel at the bottom where mosquitos could breed. However, for large-scale drainage projects, the ditches usually have a bottom width equal to or greater than the depth. This is primarily based on considerations of hydraulic efficiency (see section 4.2 above). Two typical cross-sections of drainage ditches are shown in Fig. VII-9.

Fig. VII-9. Two typical cross sections of drainage ditches.



The side slope of a ditch depends largely on the type of soil involved. Fine grained soils, such as clay, will tolerate a much steeper slope than the coarser textured soils. Even for clay, a side slope steeper than 1:1 is not recommended (except for very small ditches) because of the tendency of a ditch bank to "slide in" or "cave-in" after becoming wet. In coarser textured soils a 2:1 slope may be advisable, and very sandy soils may require slopes of 3:1.

The grade (or gradient) of a ditch is to a great extent dictated by local topographic conditions, i.e., the available fall (difference in elevation) and the general ground slope in the area concerned. The grades used for drainage ditches range from 0.0005 to 0.006, i.e., 0.5 m to 6 m fall per 1000 m length.

The flow velocity in a drainage ditch is usually designed to avoid either undue erosion or excessive silting. It therefore depends largely on the soil texture if unlined, or on the type and material of lining if lined. Very soft soil or sand may erode with velocities less than 0.3 m/sec, while firm soils may tolerate velocities of 1.5 m/sec. Under average conditions, velocities of 0.3-0.9 m/sec have proved to be satisfactory (see Table VII-2).

As the flow velocity is greatly affected by the ditch gradient, it is often difficult to obtain a reasonably high ditch velocity in flat land. Where the desired fall is not available,

the flow will be sluggish, and silting and the growth of aquatic vegetation will usually be increased, thereby requiring more maintenance.

Table VII-2. Maximum velocities that are safe against erosion

Type of soil	Mean velocity (m/sec)
Very fine loose sand	0.23-0.30
Fine loose sand	0.30-0.45
Coarse sand or light sandy soil	0.45-0.60
Average sandy soil	0.60-0.75
Sandy loam	0.75-0.85
Average loam, alluvial soil, volcanic ash	0.85-0.90
Firm loam, clay loam	0.90-1.15
Stiff clay soil, ordinary gravel soil	1.20-1.50
Coarse gravel, cobbles, shingles	1.50-1.85
Conglomerates, cemented gravel, soft slate, tough hard-pan, soft sedimentary rock	1.85-2.45
Hard rock	3.00-4.50

In steep terrain, "drop structures" will be required to dissipate the energy due to the flow and to avoid having a ditch grade resulting in velocities above the safe limit for the local soils that would cause erosion, collapse of the banks, scouring of the bed and other damage.

For the drainage of large areas, the cross-sectional area of a ditch is determined on the basis of the carrying capacity required and the flow velocity. The latter, in turn, depends on the gradient available. The shape and dimensions of the ditch cross-section are usually fixed by taking into consideration the desired side slope, the hydraulic efficiency, and the convenience for work. Examples showing the procedures for designing drainage ditches are given in section 4.3.2 below.

To facilitate excavation, stakes about 1 m long are placed at regular intervals of about 30 m along the proposed alignment to mark the centre line of the ditch. Elevations of the ditch bed at each stake are computed and the stakes are marked to indicate the constant height above the ditch bed. The equally spaced stakes can also be used for work distribution, so that each labourer gets an equal task. In short ditches, 50-100 m long, these stakes are enough for guiding the excavation of the ditch; for longer ditches the use of frames, as explained in subchapter IIIE, section 5, is indicated.

Before the ditch is excavated, a strip of land about 2 m wider than the top width of the ditch should be cleared of thick vegetation, rocks and other obstacles.

It is a good practice, particularly when employing unskilled people, to first dig a shallow trench, check the correctness of the slope and then proceed to the definitive ditch depth. A way to check the uniformity of the slope is to pour in a few buckets of water and observe if it runs evenly along the whole ditch.

So that the labourers may work on dry ground, a few metres of the ditch on the pool side are the last to be dug; when the ditch is finished and the slope has been checked for evenness, the earth that holds the water in the pool is removed gradually. As the water rushes through the ditch it washes away any obstruction in its course.

The spoil banks of a ditch should be moved back from the edge so as to leave a "berm"^a that is sufficiently wide to prevent the rainfall from washing the spoil back into the ditch as well as the weight of the spoil from causing the caving-in of the supporting bank. Alternatively, the spoil may be spread over a wider area to reduce its height and the corresponding unit area pressure on the supporting ditch bank; in this case, the wider spoil bank should be graded so that the rain which may fall upon it will run off the outside rather than towards the excavation. Smoothing the top of the spoil bank, while the recently excavated earth is still soft, involves only a little extra labour and may greatly facilitate any subsequent inspection or spraying of the ditch since the inspectors or spraymen can walk easily and quickly down the graded spoil bank instead of stumbling along a rough, overgrown unfinished bank.

Where the ditches run across a slope rather than down the fall line, the spoil should be placed on the downgrade side in a continuous pile, particularly where the ditch line crosses low areas, to serve as a levee during the times when the normal capacity of the waterway may be exceeded by flood flows. If the spoil bank must be placed on the upgrade side, openings should be left in it at intervals so that the runoff from higher land will not be trapped behind the spoil.

4.3.2 Design of drainage ditches: some examples

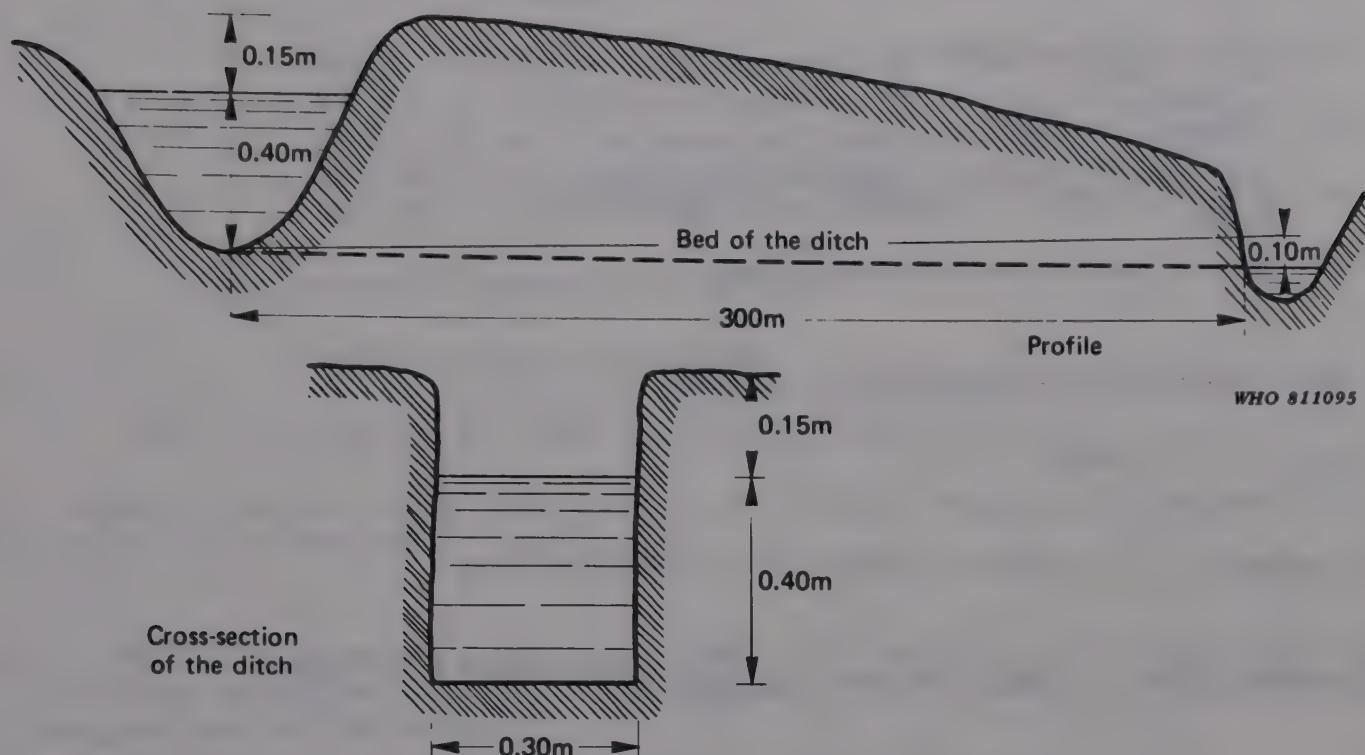
The following examples are worked out using Manning's formula in calculating the flow velocity in the drainage ditch. See section 4.2 of this chapter for details of Manning's formula.

Example 1. A pond, 0.40 m at the deepest point, contains 80 m^3 of water which is a mosquito source. From the levelling work it is found that the water can be discharged into a stream 300 m away and that the fall in elevation from the pond bottom to the water level in the stream is 0.10 m. Design the drainage ditch.

Step 1. Assume the ditch in cross-section is 0.3 m wide with 0.4 m water depth and 0.55 m overall depth (see Fig. VII-10). This is practically the smallest "workable" section for hand-dug ditches.

^a See Fig. VII-9. The berm should have a slight fall towards the ditch to prevent ponding after floods.

Fig. VII-10. Example of the procedure for designing a drainage ditch.



Step 2. Calculate the carrying capacity of the ditch by the use of Manning's formula as follows:

(1) When the pond is at full depth:

$$\text{the cross-sectional area of the ditch, } A = 0.3 \times 0.4 = 0.12 \text{ m}^2$$

$$\text{the wetted perimeter, W.P.} = 0.4 + 0.3 + 0.4 = 1.1 \text{ m}$$

$$\text{the hydraulic radius, } R = \frac{A}{W.P.} = \frac{0.12}{1.1} = 0.109 \text{ m}$$

$$\text{the hydraulic gradient, } S = \frac{0.4 + 0.1}{300} = \frac{0.5}{300} = 0.00167$$

$$\text{the roughness coefficient for unlined earth canal, } n = 0.025$$

$$\text{the mean velocity, } V = \frac{1}{n} \times R^{2/3} \times S^{1/2} = \frac{1}{0.025} \times 0.109^{2/3} \times 0.00167^{1/2} \\ = 0.373 \text{ m/sec}$$

$$\text{average rate of discharge } Q = AV = 0.12 \text{ m}^2 \times 0.373 \text{ m/sec} = 0.0448 \text{ m}^3/\text{sec}$$

(2) When the pond is drained to half depth:

$$A = 0.3 \times 0.2 = 0.06 \text{ m}^2; \text{ W.P.} = 0.2 + 0.3 + 0.2 = 0.7 \text{ m}$$

$$R = \frac{A}{W.P.} = \frac{0.06}{0.7} = 0.0857 \text{ m}$$

$$S = \frac{0.2 + 0.1}{300} = 0.001$$

$$V = \frac{1}{0.025} \times 0.0857^{2/3} \times 0.001^{1/2} = 0.246 \text{ m/sec}$$

$$Q = AV = 0.246 \times 0.06 = 0.0148 \text{ m}^3/\text{sec}$$

(3) When the pond is almost totally drained:

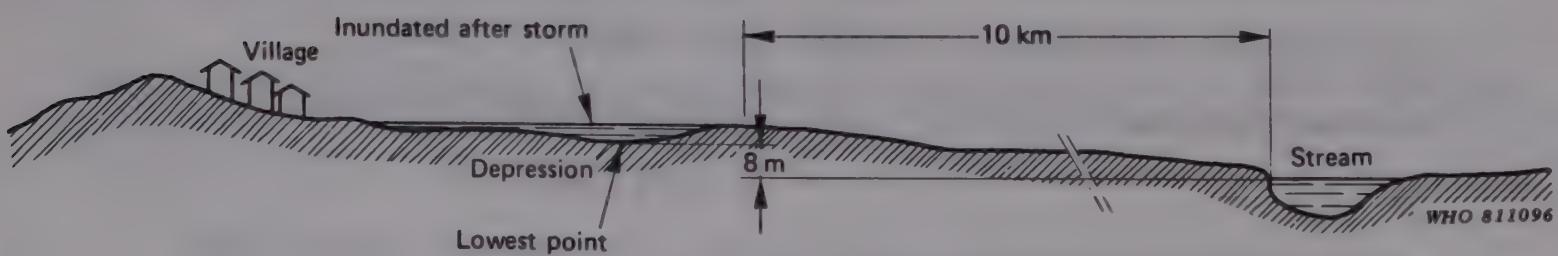
$$A = 0, V = 0 \text{ and } Q = 0$$

$$(4) \text{ Average } Q = \frac{1}{3} (0.0448 + 0.0148 + 0) = 0.0199 \text{ m}^3/\text{sec}$$

$$(5) \text{ Approx. time to drain the pond} = \frac{80}{0.0199} + 60 + 60 = 1.12 \text{ hours}$$

(6) It will be noted that, with a ditch of the smallest practicable cross-section, a rainfall pond will be drained in a little over an hour, while the water could be stagnant there for 7-10 days^a without creating mosquito breeding problems. It is thus clear that for the drainage of small unfed (surface or ground water) water collections, there would be no need to calculate the ditch size; any ditch that can be conveniently dug would be more than sufficient for the purpose.

Example 2. A village located in a valley gets flooded after heavy rains because of its rather low and enclosed topography. A stream is about 10 km away and has a high-water level about 8 m below the lowest point of the valley. The watershed area contributing runoff to the valley is 75 hectares. Protection is desired against a rainfall of 130 mm/hour, for a duration of 1½ hours. Design the drainage ditch.



^a In this example, it is assumed that the local anopheline vectors would require approximately 2 weeks to develop from the egg to the adult stage.

Step 1. Calculate the volume of water to be drained. An approximation of the runoff from a small drainage area such as the one in this example can be made using the "rational method", which is expressed by the formula $Q' = \frac{1}{360} CIA$

where Q' = runoff in m^3/sec ;

C = runoff coefficient representing the ratio of the rate of runoff to the rate of rainfall. The value of C ranges from 0.10 for flat areas and high pervious soil to 0.40 for small agricultural watersheds in rolling countryside to 0.95 for city pavements and roofs;

I = rainfall intensity in mm/hour ;

A = watershed area in hectares.

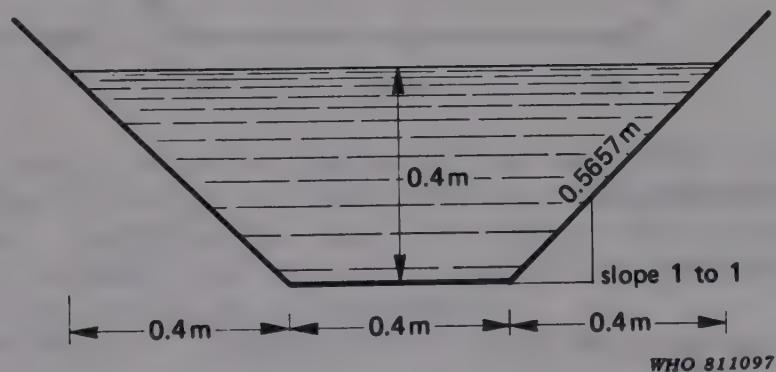
$$\text{Thus, } Q' = \frac{1}{360} \times 0.4 \times 130 \times 75 = 10.83 \text{ m}^3/\text{sec.}$$

For a rainfall duration of $1\frac{1}{2}$ hours, the total volume of water to be drained is $10.83 \times 1.5 \times 60 \times 60 = 58482 \text{ m}^3$.

Step 2. Design the cross-section of the ditch. For mosquito control purposes, this volume of water can be drained in say 7 days^a without creating mosquito breeding problems. Thus the required rate of discharge :

$$Q = \frac{58482}{7 \times 86400} = 0.0967 \text{ m}^3/\text{sec}$$

Assume an unlined earth ditch of the following cross-section:



$$A = \frac{1.2 + 0.4}{2} \times 0.4 = 0.32 \text{ m}^2; \quad W.P. = 0.5657 \times 2 + 0.4 = 1.5314 \text{ m}$$

$$R = \frac{A}{W.P.} = \frac{0.32}{1.5314} = 0.2090 \text{ m}; \quad S = \frac{8}{10000} = 0.0008$$

$$n = 0.025$$

$$V = \frac{1}{n} \times R^{2/3} \times S^{1/2} = \frac{1}{0.025} \times 0.2090^{2/3} \times 0.0008^{1/2} = 0.3984 \text{ m/sec}$$

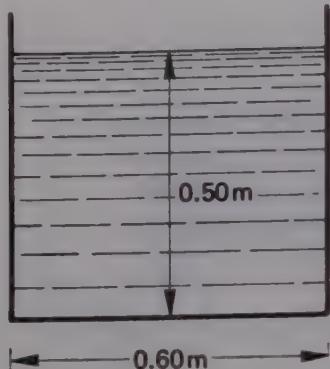
$$Q = AV = 0.32 \times 0.3984 = 0.1275 \text{ m}^3/\text{sec}$$

which is slightly greater than the required rate of discharge and therefore should usually be satisfactory.

^a In this example, it is assumed that the local anopheline vectors would require approximately 10-14 days to develop from the egg to the adult stage.

1006

If the soil is such that the sides of the ditch can be vertical, perhaps a hand-dug ditch of a rectangular section (0.6 m wide x 0.5 m deep) would provide a simpler solution.



$$A = 0.5 \times 0.6 = 0.30 \text{ m}^2, R = \frac{0.30}{0.5 \times 2 + 0.6} = 0.1875 \text{ m}$$

$$V = \frac{1}{0.025} \times 0.1875^{2/3} \times 0.0008^{1/2} = 0.3706 \text{ m/sec}$$

$$Q = AV = 0.30 \times 0.3706 = 0.1112 \text{ m}^3/\text{sec.}$$

However, if drainage is required for crop protection, the accumulated water will need to be removed say in 2 days, instead of in 7 days as required for mosquito control alone. A much larger ditch will be needed as shown by the following calculations:

(a) If unlined ($n = 0.025$):

$$\text{The required rate of discharge} = \frac{58482}{2 \times 86400} = 0.3384 \text{ m}^3/\text{sec}$$



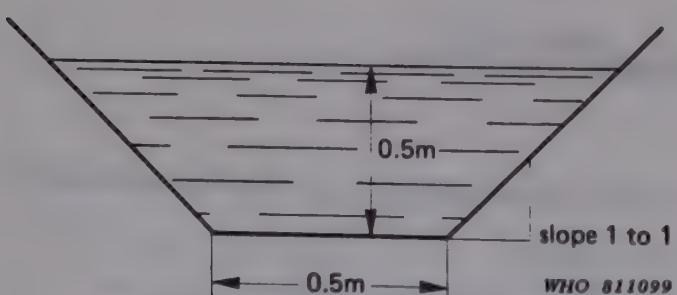
$$A = 0.7425 \text{ m}^2$$

$$R = 0.3152 \text{ m}$$

$$V = \frac{1}{0.025} \times (0.3152)^{2/3} \times (0.0008)^{1/2} = 0.5240 \text{ m/sec}$$

$$Q = 0.3890 \text{ m}^3/\text{sec}$$

(b) If lined by brickwork ($n = 0.015$):



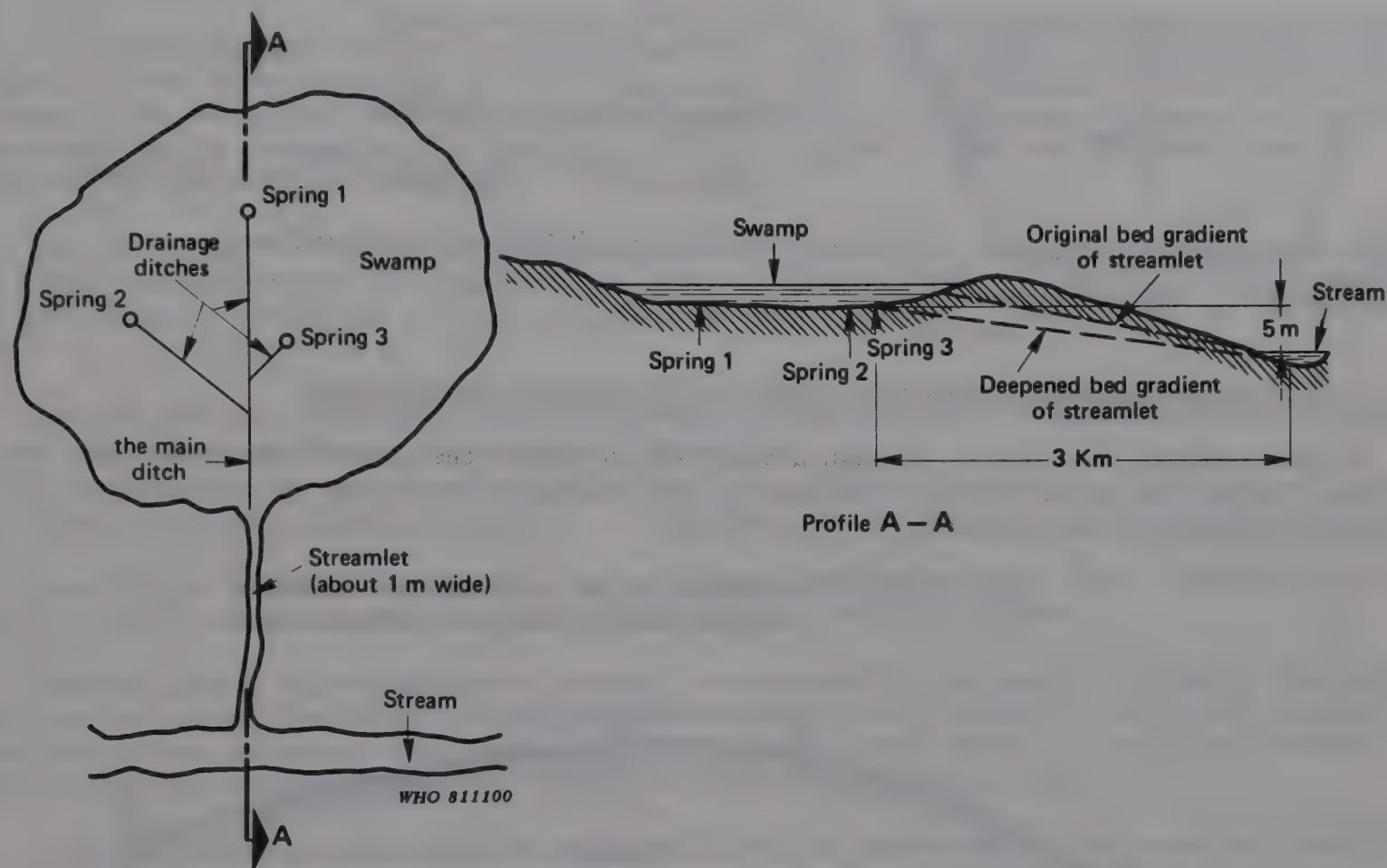
$$A = 0.500 \text{ m}^2$$

$$R = 0.2612 \text{ m}$$

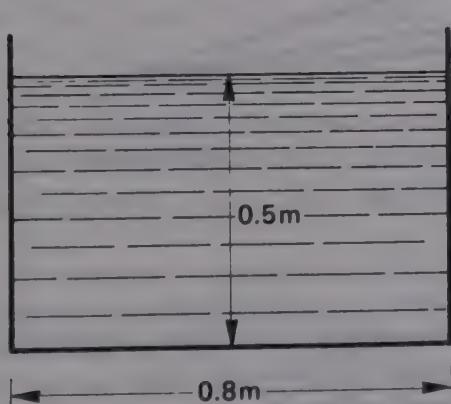
$$V = \frac{1}{0.015} \times (0.2612)^{2/3} \times (0.0008)^{1/2} = 0.7705 \text{ m/sec}$$

$$Q = AV = 0.3853 \text{ m}^3/\text{sec}$$

Example 3. A swamp, fed by three springs, is creating mosquito breeding problems (see sub-chapter IIIE, section 4.2.3). The maximum yield of each spring is found to be 80 l/sec. Detailed data on the situation are given in the sketch below. It is decided to completely dewater the swamp. Design the main drainage ditch and propose measures for improving the streamlet.



If the swamp is to remain dry after draining, the main ditch must be designed and the streamlet must be deepened in such a way that they will carry away the water as soon as it comes out of the springs. Therefore the main ditch should have a capacity of $80 \times 3 = 240$ l/sec, or $0.240 \text{ m}^3/\text{sec}$. Assuming that the soil is such that vertical ditch sides will be stable, the following ditch section will be adequate.



$$A = 0.40 \text{ m}^2$$

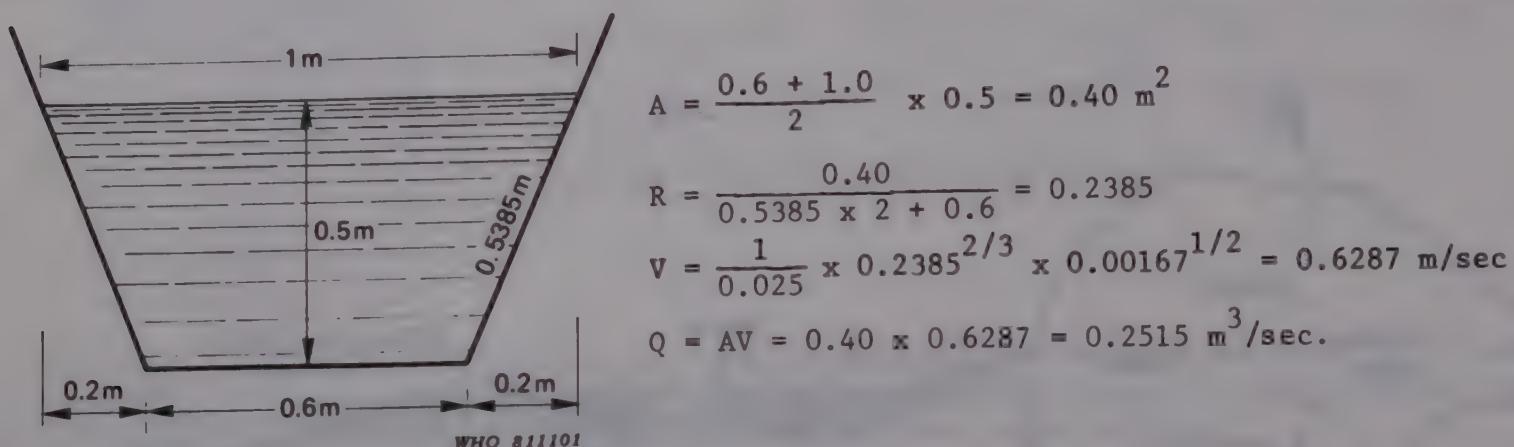
$$R = \frac{0.40}{0.5 \times 2 + 0.8} = 0.2222 \text{ m}$$

$$S = \frac{5}{3000} = 0.00167$$

$$V = \frac{1}{0.025} \times 0.2222^{2/3} \times 0.00167^{1/2} = 0.5997 \text{ m/sec}$$

$$Q = AV = 0.40 \times 0.5997 = 0.2399 \text{ m}^3/\text{sec.}$$

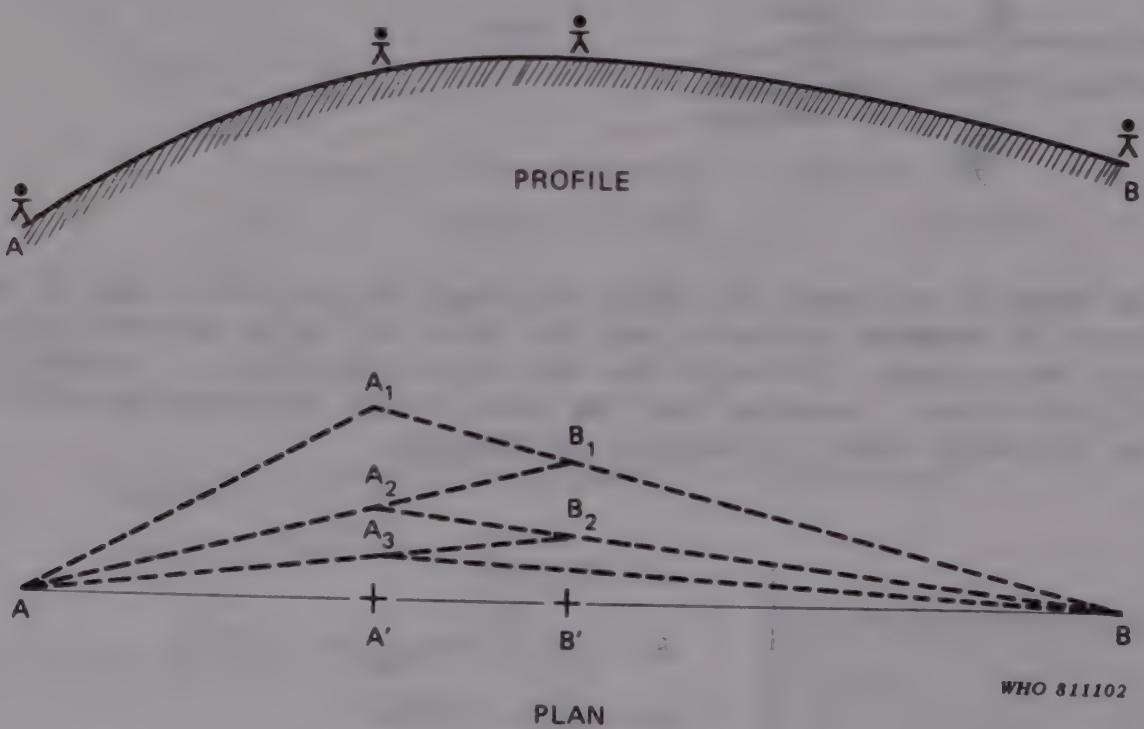
The streamlet needs to be deepened, in particular, at the junction with the swamp, and its bed needs to be appropriately graded to a slope of 5/3000. Its cross-section at any point should not be smaller than the following: (Note that the original top width of the streamlet is about 1 m).



4.3.3 Setting an alignment between two points which are not within sight

In case a drain line passes through a mound which blocks the sight between the two reference points one on each side of the mound, the alignment can be set by a procedure of successive corrections as explained in Fig. VII-11.

Fig. VII-11. Procedure to set an alignment between two points which are not within sight.



Point A is not visible from point B and vice versa.

Two men stand in A and B respectively, and two other men move into the intermediate area so that both can be seen from A and B. The man in A sets his man at A_1 ; the man in B moves his man to B_1 so that A_1 and B_1 are aligned with B. The man in A moves his man to A_2 so that B_1 and A_2 are aligned with A. The man in B moves his man to B_2 so that A_2 and B_2 are aligned with B. And so on until the four men are on a straight line.

4.4 Improvement of shorelines

When water collections cannot be filled or drained, either because of their large extent or their useful purpose, it is still possible to modify the conditions that favour mosquito breeding by certain environmental management works described in subchapter IIIA. These include vegetation clearance on lake and reservoir shorelines, and the rectification of the shoreline by cut and fill methods.

To straighten the shoreline it is convenient to begin by cutting the material from the projecting land where it is dry and above the water level. This material can be used to form a levee along the chosen new shoreline to hold the wetter material which is later on dug and discharged on the inland face of the levee. The filling will gradually progress from the levee toward the original shoreline.

The calculation of earth volumes is complicated by the fact that the ground slopes above and below the water level are usually very different within short distances; added to this, the wet material shrinks as it dries and much of it is lost when it is carried to the site of use.

The mud and wet earth used for filling may crack as they dry. When filled with rainfall or run off, these cracks may allow mosquito breeding.

4.5 Some basic facts about concrete

Concrete is a mixture of water, Portland cement and aggregates. Sand is normally used as the fine aggregate and gravel or crushed stone as the coarse aggregate.

Concrete has a high compressive strength, compared with its tensile strength. To compensate for the rather low tensile strength, concrete is usually reinforced with steel bars on that side of the structure component (e.g., a beam or a slab) which is subject to tension. This is called reinforced concrete; plain concrete has no reinforcing bars.

The high strength-cost ratio of concrete (plain or reinforced, as the case may require) is one of its most important advantages and the major reason for its wide use.

As a measure of concrete strength, which increases with age over a long period of time, the compressive strength at 28 days is commonly used. It is general practice to determine this strength by testing specimens in the form of standard cylinders made in accordance with applicable specifications. A "3000 psi concrete" or a "200 kg/cm² concrete" refers to the compressive strength of the concrete at 28 days after being cast.

Concrete strength is influenced chiefly by the water-cement (w/c) ratio; the higher this ratio, the lower the strength. In fact, the relationship is approximately linear (see Fig. VII-12).

For economy, the amount of cement used should be kept to a minimum. Generally, this is facilitated by selecting the largest-size coarse aggregate consistent with job requirements and good gradation. The smaller the volume of voids, less cement paste is needed to fill them.

To obtain a concrete mix of a given strength (i.e., with a given water-cement ratio), the less water used in the mix the less cement will be required, provided the characteristics and proportions of the aggregates remain unchanged. However, a concrete mix with too little water tends to be dry and stiff, and may not have a workability^a suitable for the intended job.

^a Workability, in essence, is the ease with which the ingredients can be mixed and the resulting mix handled, transported and placed with little loss in homogeneity.

Therefore, the amount of mixing water is governed mainly by the required workability of the final mix.

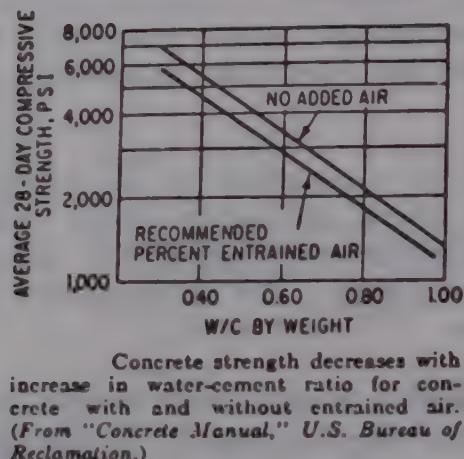


Fig. VII-12

A concrete mix is normally proportioned by weight. For small jobs, however, it is often proportioned by volume and is indicated shortly by the ratio of cement to sand to coarse aggregate (e.g., 1:2:4 or 1:3:6) plus the minimum cement content per unit volume of concrete (cu. yard or cu. m.).

For small jobs and where concrete mixers are not available, concrete can be mixed by hand, but thorough mixing must be ensured. During concrete placement, precautions should be taken to prevent segregation when it is being transported and dumped into place.

The setting (or hardening) of concrete after being cast is a chemical process which requires water for hydration. Drying out the concrete after the initial set may prevent complete hydration and hence reduce its ultimate strength. Exposed concrete surfaces should therefore be kept continuously moist, usually by spraying or ponding or by a covering of moist earth, sand, or burlap. This process is called "curing".

Formwork retains concrete until it has set and produces the desired shapes. The contractors usually wish to remove the forms rather early for quick re-use. While this might be acceptable in the case of forms on the sides of beams, walls, etc., the forms and supports under beams and floors should not be removed until the concrete has attained sufficient strength to carry at least its own weight. Details of formwork for concrete can be found in various reference books and manuals.^a

5. Plane surveying for environmental management works for vector control

The procedures and methods described here do not necessarily represent the only or the most practical solutions to surveying problems. Depending upon the individual, the results desired, and the attendant circumstances, other "short-cut" methods may be applicable which would result in a satisfactory solution with less effort.

^a Peurifoy, R.L. Formwork for concrete structures, 2nd ed., New York, McGraw Hill, 1976. ACI manual of concrete inspection, 6th ed., Detroit, American Concrete Institute, 1975. Formwork for concrete, Detroit, American Concrete Institute, 1973.

5.1 Definitions

5.1.1 Plane surveying and geodetic surveying

The art of measuring and locating lines and angles on the surface of the earth is called surveying.

When the survey is of such limited extent that the effect of the earth's curvature may be safely neglected, the term plane surveying is used.

Geodetic surveying takes into account the effect of the earth's curvature as in the survey of a state or country.

Surveys are made for a variety of purposes, such as the determination of areas, the fixing of boundary lines, the plotting of maps, and for engineering construction works, highways, railroads, bridges, buildings, irrigation and drainage systems, land levelling, etc.

5.1.2 Measurement of lengths and direction

In surveying, all measurements of length are horizontal or else are subsequently reduced to horizontal distances. In addition to determining the length of a survey line, its direction also must (in many cases) be determined. The direction of a line is determined with reference to the direction of a magnetic needle (as of a compass) which possesses the property of pointing in a fixed direction, namely, the magnetic meridian. This direction is expressed in terms of an angle called the magnetic bearing of the line, or simply its bearing. A bearing reckoned from the geographical meridian is called the true bearing or azimuth and, in general, will not coincide with the magnetic bearing of the line. The angle between the magnetic meridian (the fixed direction of the magnetic needle) and the true (geographical) meridian is called the declination of the needle. For example, this declination varies from 0° to as much as 24° in various locations in the United States and may be either east or west of the true north depending on the location.

The two principal instruments employed in measuring distances are the steel tape (of 10-50 m lengths) and a telescope on a transit or level which is equipped with a set of stadia hairs. In present-day surveying, the electronic distance meter (EDM) is also often used for large-scale precision jobs.

The surveyor's compass is the principal instrument used in measuring the direction of lines. Most transits and some levels are equipped with a compass. The horizontal circle of the compass is graduated to the degree or the half-degree and numbered from two opposite zero points each way to 90° . The zero points are marked with the letters N and S and the 90° points are marked E and W.

The magnetic bearing of a line is reckoned from 0° to 90° , the 0° being either at the N or the S point and the 90° either at the E or the W point. The quadrant in which a bearing falls is designated by the letters NE, SE, SW, or NW (see Fig. VII-13). The magnetic bearing of the line OA in this figure is N $61^\circ 05'$ E.

The true bearing of a line is usually reckoned^a from the south point, round clockwise to 360° ; thus, a line running due west has an azimuth of 90° and a line due north has an azimuth of 180° . In Fig. VII-13 the azimuth of the line OA is $242^\circ 15'$.

^a Another system of azimuth is to measure the angle clockwise from the north, instead of from the south.

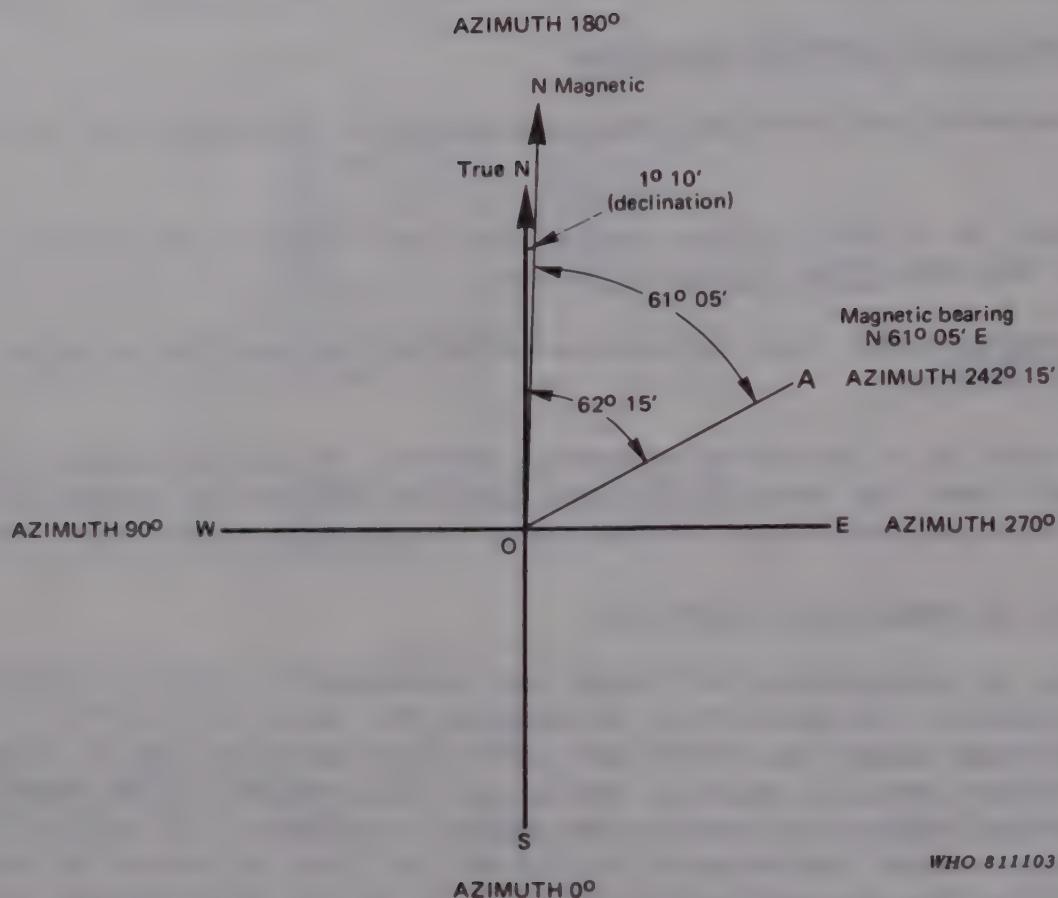


Fig. VII-13. Direction of a line.

5.1.3 Measurement of angles

After the magnetic bearings of two lines have been determined by use of the surveyor's compass, the angle between the two lines can be calculated by addition or subtraction, or a combination of these simple mathematical computations. However, for more accurate results in measuring horizontal (and vertical) angles an engineer's transit should be used.

5.1.4 Measurement of elevation

A level surface is really a curved surface which at every point is perpendicular to the direction of gravity at that point, such as the surface of still water, for example. Any line of sight which is perpendicular to the direction of gravity at a given point is therefore tangent to the level surface at that point and is called a horizontal line.

The elevation of a point is the height of the point reckoned from some zero plane, such as mean sea level. The plane is called the datum and its elevation is always zero. If mean sea level is not known, a datum can be arbitrarily assumed. This is particularly applicable for short or limited surveys which will not have to be "tied in" to an existing or future survey. For the sake of convenience in recording and later interpreting the survey data, the assumed datum plane (to which surface elevations are referred) should lie below the lowest point likely to be reached on the survey.

A bench mark (B.M.), or simply bench, is a permanent mark whose elevation above the datum plane is accurately known. It may be a bolt or similar object set into the top of a solidly fixed stone or simply a mark on a stone, a tack driven into a projecting root of a tree, or the top of some concrete structure such as a culvert headwall or similar irrigation works structure.

5.2 Levelling

The process of finding the difference in elevation of any two points is called differential levelling. Levelling for the purpose of determining the changes in elevation of the surface of the ground along some definite line is called profile levelling. In elementary surveying and for most ordinary surveying problems, the direct levelling method is used. Trigonometric levelling is used only in advanced surveying work and takes into account vertical angles.

The instrument chiefly used for the direct determination of differences of elevation is the level, in combination with the levelling rod. There are three principal types of level: the Wye level, the Dumpy level and the hand level. For more accurate measurements the two former types are used, the hand level being used only when approximate levels are desired. The engineer's transit, which has the long level attached to the telescope, is frequently used for rough levelling.

A commonly used levelling rod is the self-reading type with graduations in either the metric or the English system. The graduation lines are 1 cm wide in the metric system and 0.01 ft in the English system. The rod is graduated from 0 at the lower end to 3 m (or 7 ft in the English system) or higher by extending at its upper end (see Fig. VII-14).

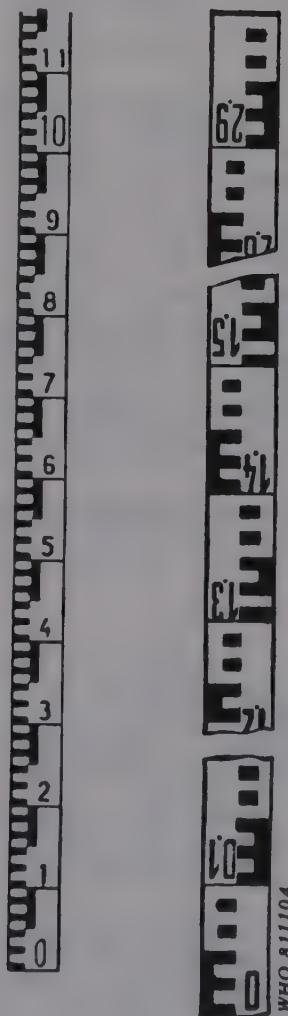


Fig. VII-14. Levelling rods.

5.2.1 Levelling procedure

The first step in beginning a survey which involves elevations (vertical distances) is to establish the first bench mark and record its elevation. The instrument (level or transit) is firmly set up at a moderate distance from the bench so that the telescope is somewhat higher than the bench and commands a full view of a rod held vertically upon it. The instrument is properly adjusted so that the level bubble stands in the centre of its tube (and the vertical circle reads zero for a transit) during an entire revolution of the telescope about the vertical axis. With the instrument so adjusted, the line of sight through the intersection of the telescope's cross-hairs is known to be horizontal. The rod is held vertically upon the bench, the line of sight of the telescope is turned upon the rod, and the point on the rod intercepted by the horizontal cross-hair (reading of the rod) is known to be level with the cross-hair. Therefore, the cross-hair is higher than the bench by the distance intercepted on the rod from its lower end. Adding this distance to the elevation of the bench gives the elevation (above the datum) of the horizontal cross-hair, or height of instrument (H.I.).

Once the height of instrument has been determined, the elevation of any point lower than the cross-hair by a vertical distance (not exceeding the length of the rod) is easily ascertained. The rod reading, subtracted from the H.I., gives the elevation of the point above the datum.

But the elevation of points on ground higher than the cross-hair, or farther below it than the length of the rod, cannot be determined because in either case the line of sight will not cut the rod, and hence there can be no reading. To observe such points, the instrument must be moved to a new position, higher or lower than before, as the case may require, and the new H.I. determined.

Before moving the instrument to a new position, however, a temporary bench called a turning point (T.P.) must be established and its elevation ascertained as for any other point but with more accuracy. The reading having been taken and recorded for the T.P. (to obtain its elevation), the instrument is carried forward to a new point and there properly levelled. A new rod reading is taken on the same T.P. and added to the T.P. elevation for the new height of the instrument. The elevation of additional points within the vertical range previously described and within practical horizontal distances from the instrument may now be determined simply by reading the rod on the points. Readings on bench marks and turning points should be to the nearest millimetre to ensure the accuracy desired. Elevations on the surface of the ground will not usually be needed closer than to the nearest centimetre or half centimetre.

To find the height of the instrument, add the reading on a point to the elevation of the point; and to find the elevation of a point, subtract the reading on it from the height of the instrument (see Fig. VII-15).

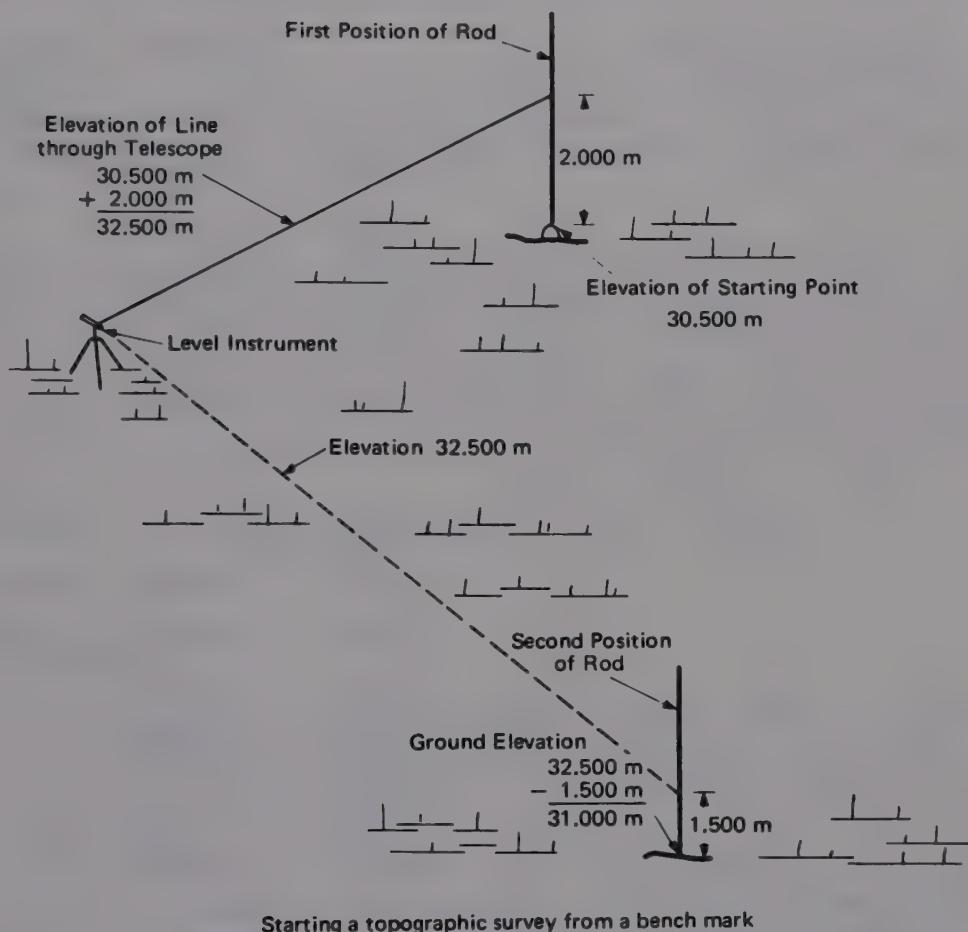
A reading taken for the purpose of finding the height of the instrument is called a backsight (B.S.), and a reading taken for the purpose of finding the elevation of a turning point or any other point is called a foresight (F.S.). Hence backsights are always plus (+S) and foresights are always minus (-S). The terms backsight and foresight, as used here, do not necessarily refer to the directions in which the sights are taken.

5.2.2 Profile levelling

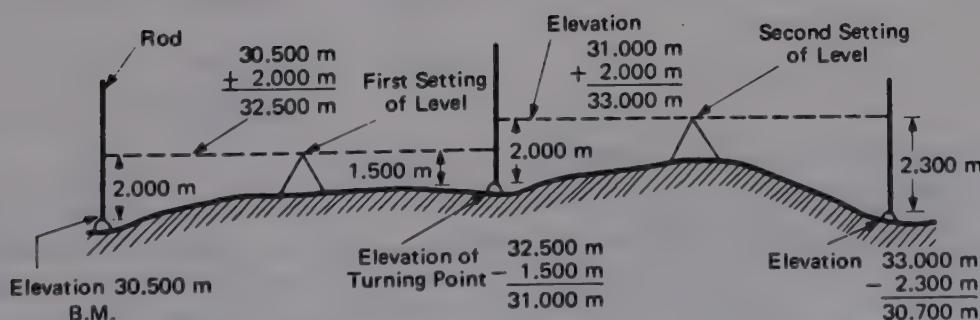
Profile levelling is used for the purpose of obtaining data which indicate the changes in elevation of the surface of the ground along some definite line, and from which a profile or vertical section may be developed, showing in detail the rises and falls of the surface over which it passes. From such a profile, a grade can be established and design for construction may be made. The line is first "stationed", i.e., marked at a certain interval, usually every 30 m, by stakes upon which the station number is written. Surveys for drainage are usually begun at the lower or downstream end, unless there is some doubt as to the location of an adequate outlet in which case the survey would begin upstream and extend to the point of

satisfactory outlet as determined by the levels. The instrument is set up and the H.I. determined, as previously described. Foresights are then read on as many station points on the line as can conveniently be taken from the position of the instrument. Intermediate sights are taken at any points where marked changes of slope occur and the "plus" (+) stations of these intermediate points are recorded with the rod readings. The instrument is moved forward as is necessary and this general process is continued until the end of the line is reached.

Fig. VII-15. Profile levelling



Starting a topographic survey from a bench mark



WHO 811105

Moving instrument while making a topographic survey

The level notes may be kept in any convenient form that is easily understood by the note-keeper or any others who may have to interpret them. The development of satisfactory and workable plans for a construction job depends largely upon the surveying notes and data available. Table VII-3 gives a form of profile levelling notes.

Table VII-3. Profile level notes
(metric units)

Station	B.S. (+)	H.I.	F.S. (-)	Rod	Ground elev.	Description
B.M.1	1.460	101.460			(100.000)	Nail in red oak 18 m Rt. Sta. 0 + 00
0				2.955	98.505	
1				1.550	99.910	
2				1.495	99.965	
+ 20				1.830	99.630	
3				1.195	100.265	
T.P. (B.M.2)	2.295	101.010	2.745		(98.715)	Top Rt. D.S. wingwall hwy.
4				1.765	99.245	culvt. 15 m Lt. Sta.
5				2.075	98.935	3 + 19
6				2.135	98.875	
7				2.350	98.660	
8				2.500	98.510	
9				2.780	98.230	
T.P. (B.M.3)	1.250	100.105	2.155		(98.855)	Nail in tp. cypress stump 10 m Rt. Sta.
10				2.175	97.930	9 + 8
11				2.325	97.780	
+ 10			2.420		97.685	
	5.005		7.320			

The additions and subtractions made on each page of the notes should be proved before proceeding to the calculations of the next. When correct, the difference of the sums of the B.S.'s and F.S.'s on the page equals the difference of the first and last elevations on the page, if the last rod reading is shown as an F.S. Thus, in the example given in Table VII-3, $7.320 - 5.005 = 2.315 = 100.000 - 97.685$.

In this proof, all elevations except those for T.P.'s and B.M.'s, used as such, and the last point on the page are ignored.

A line of levels should be checked by connecting with some reliable bench mark, if possible. Bench marks along the line of levels should be used as turning points, if convenient, or at least check readings should be taken on them in order to detect mistakes.

5.2.3 Establishing grades

By utilizing the level notes, the profile is plotted on profile paper printed for the purpose (see Fig. VII-16). A horizontal scale of 1 to 1000 and a vertical scale of 1 to 100 are commonly used in road and drainage work. This distortion of scale magnifies the vertical measures so that slight changes in the elevation of the surface may be distinctly seen on the profile paper.

A line which is drawn on a profile to correspond to the finished surface of a road, or the flow line of a ditch or a canal, is called the grade line. Many factors must be considered in designing the grade lines for construction projects and such factors vary widely depending upon the type of project.

The gradient is the rate of change of elevation in the grade line and is usually expressed as a percentage. Thus a 1.7% gradient indicates a rise or fall of 1.7 m in a horizontal distance of 100 m. When the grade is ascending, the gradient is marked plus (+); and when descending, minus (-). The word grade is frequently used instead of gradient. In the example given above, the gradient will be approximately - 0.24% which represents the ratio of the difference of elevation to the distance between the first and last stations

$$\frac{(97.685 \text{ m} - 98.505 \text{ m})}{340.000} \times 100 = - 0.24\%$$

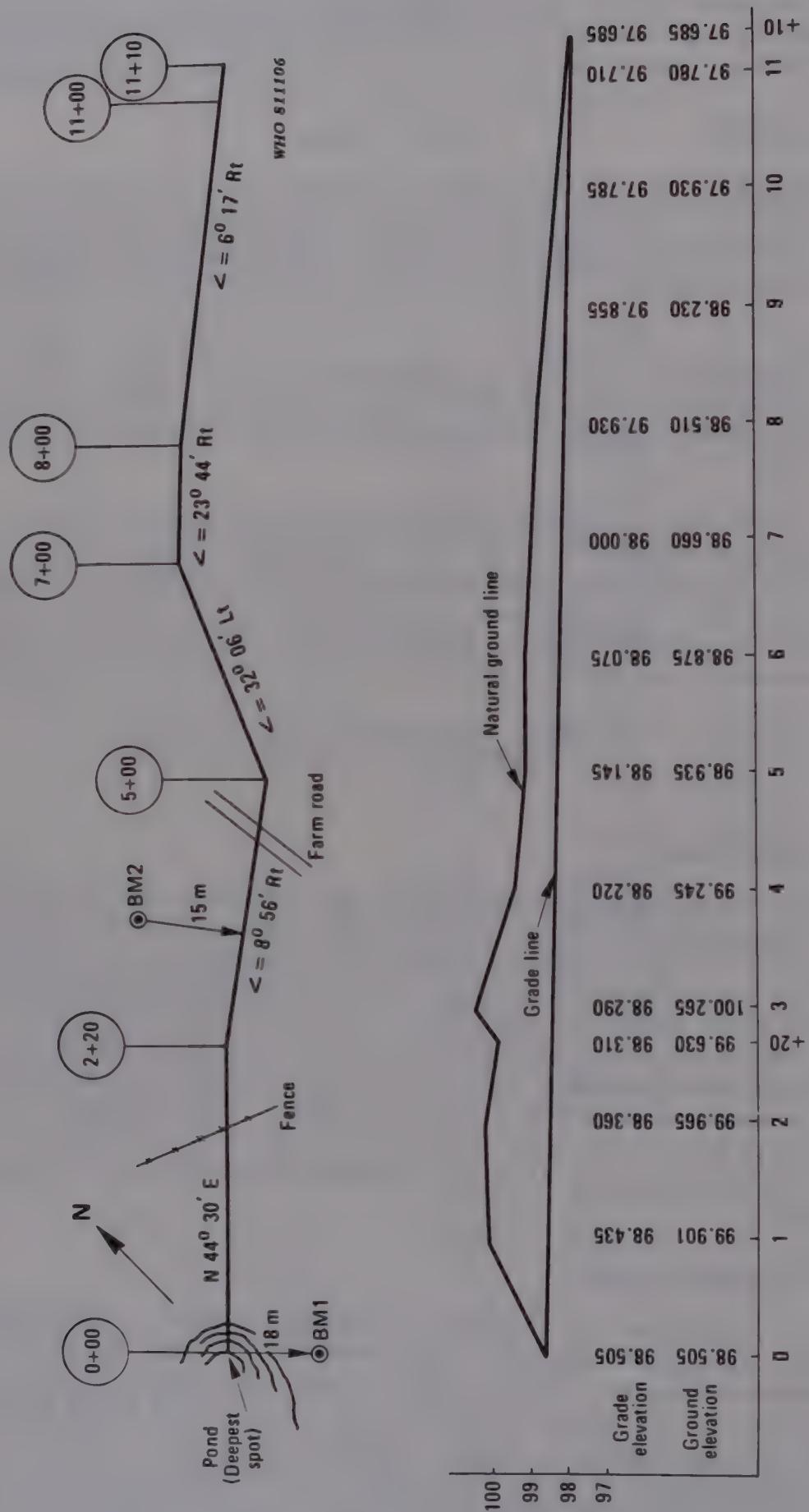
5.2.4 Cross-section levelling

In practically all railroad and highway work and for large canals or ditches it is necessary to run cross-section levels. The data thus obtained are utilized in estimating the quantity of earthwork required. Cross-sections for this purpose are usually taken at full station points of the line usually 30 m apart, or more often if the longitudinal slope changes considerably, and at right angles to the centre line of the proposed road, canal or ditch. For smaller canals and ditches, through level or flat terrain involving excavation only, cross-sections are rarely necessary. Under these conditions, earthwork quantities may be estimated fairly accurately from the profile and grade elevations. The procedure for cross-section levelling is similar to that previously described for profile levelling. Rod readings of the points right and left of the centre line are recorded along with the distances of the points from the centre line.

5.2.5 Levelling for construction

In earth-moving operations for highways, irrigation canals, drainage ditches and land levelling, the established grade upon the final profile of a located line is the basis to which all construction work must conform. When the desired grade line has been drawn (in the office) on the profile and its grade or gradient determined, the grade elevation at each station of the line may be computed. Before construction begins, the proposed work must be "staked out" with grade stakes at every full station (usually 30 m apart) or more often on the centre line and at both sides with slope stakes where the finished slope intersects the surface of the ground (see also section 5.2.4). The amount of the "cut" or "fill" ("cut" only in drainage work) is marked on these stakes for guidance in the actual construction operations.

Fig. VII-16. Sample plan and profile sheet.



A common practice in drainage work is to offset the grade stakes either right or left of the centre line for a minimum distance equal to at least one-half the bottom width of the proposed drainage ditch, with the stake extending about 15 cm above the surface of the ground. The grade stakes then will not be disturbed while "roughing in" the ditch to the grade. Unless there is considerable transverse slope of the land along the line, it is not always necessary to mark the cut on the slope stakes - the marking of the grade stake will suffice. Slope stakes in this case serve only to mark the point of intersection of the ditch side slope with the ground line.

For determining the cuts (and fills) in the field, the level (or transit) is set up and the H.I. is determined from some convenient B.M. in the manner as previously described. The difference between the H.I. and the grade elevation at any given point (from the profile prepared in the office) is called the rod reading for grade (or simply grade rod), i.e., the rod reading which would be obtained if the lower end of the rod could be held at the given point on the flow line of the ditch, or finished surface (grade) of the road, as the case may be. Then the rod is held on top of the grade stake and a reading is taken to the nearest centimetre. The difference between this rod reading and the rod reading for grade will give the cut (or fill) at that point, as reckoned from the top of the grade stake. The cut (or fill) is marked on the grade stake which also has the station number marked on the opposite side. The first stake (station) is numbered 0 + 00, the second 1 + 00, the third 2 + 00, etc. When readings are taken at intermediate points, the stakes marking these positions will be numbered according to the number of metres each lies in advance of the preceding stake, e.g., 2 + 10 m, which means 70 m from the first station (30 m + 30 m + 10 m).

Table VII-4 illustrates one method of note-keeping in levelling for grade stakes which indicates the "cut" at the centre line only of a proposed drainage ditch.

For most open drains constructed through fairly flat or level terrain, the distance from the centre line to the point of intersection of the side slope with the natural ground surface is equal to half the ditch bottom width plus the centre line cut multiplied by the slope, the slope being the inclination of the side slope expressed in terms of the ratio of the horizontal to the vertical distance from the edge of the ditch bottom. Thus a slope which rises 1 m vertically in a horizontal distance of 1.5 m is called "a slope of 1.5 to 1". Slope stakes are set right and left of each station to mark the points of intersection with the ground. Slope stakes for adjacent stations may be connected by a string line which will provide a continuous mark for the intersection of the slope with the ground line.

Depending upon whether the excavation is accomplished by hand or machine, various methods of establishing the grade during construction are utilized. For hand-dug ditches a string line, set from grade stake data, parallel to and at a given number of metres above the established grade line, will be adequate in checking for the proper depth. Targets consisting of crossbars (batten boards) at a constant distance above the grade line serve to guide operators of machines in digging ditches (see section 5, subchapter IIIE).

This procedure for setting grade stakes is also applicable to the installation of a drain tile. A trench similar to that for open drains must be dug for the drain tile. However, no sloping is required and the trench is backfilled after the tiles are laid.

5.2.6 Substitute tools for levelling

The engineer's level is essentially a device by which a person may establish a horizontal line of sight whose precise vertical distance above a selected point of reference can be determined. From this line of sight, which may be turned towards any compass direction while still being held horizontal, downward vertical distances to any point may be measured, thereby establishing the height relationship of the second point to the first. A resourceful vector control worker who understands the principles of differential levelling can use substitute tools to obtain usable though less accurate data when a precise tripod-mounted surveyor's level (or transit) is not available.

Table VII-4. Level notes for grade stakes

Station	B.S. (+)	H.I.	F.S. (-)	Grade elev.	Grade rod	Rod	Cut	Description
B.M.1	1.311	101.311		(100.000)				
0				98.505	2.81	2.81	0	Ground elev. 98.505
1				98.435	2.88	1.40	1.48	
2				98.360	2.95	1.34	1.61	
2 + 20				98.310	3.00	1.68	1.32	
T.P.	1.738	100.453	2.596	(98.715)				B.M.2
3				98.290	2.16	0.18	1.98	
4				98.220	2.23	1.20	1.03	
5				98.145	2.31	1.51	0.80	
6				98.075	2.38	1.57	0.81	
T.P.	1.250	100.025	1.677	(98.776)				Top culvert HW, Rt. 6 + 10
7				98.000	2.03	1.37	0.66	
8				97.930	2.10	1.52	0.58	
9				97.855	2.17	1.80	0.37	
T.P.	1.034	99.889	1.171	(98.855)				B.M.3
10				97.785	2.10	1.96	0.14	
11				97.710	2.18	2.11	0.07	
11 + 10			(2.204)	97.685	2.20	2.20	0	Ground elev. 97.685
	5.333			7.648				

Check: 7.648 - 5.333 = 100.000 - 97.685

A hand level (see Fig. VII-17) is a simple instrument for levelling where high precision is not required. It is handheld at the surveyor's eye level while rod readings are made. The alidade of a plane-table set is a good instrument for measuring vertical distance with moderate accuracy (see section 5.3.3.4 below).

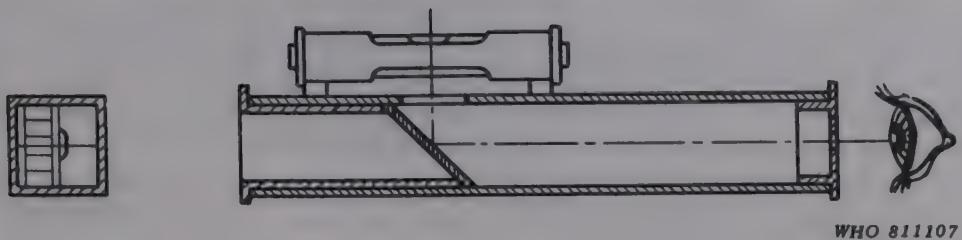


Fig. VII-17. Hand level

Should none of the above-mentioned instruments be at hand, a carpenter's level (see Fig. VII-18) may be tried following the method described below, but accurate results cannot be expected from such a rudimentary tool.

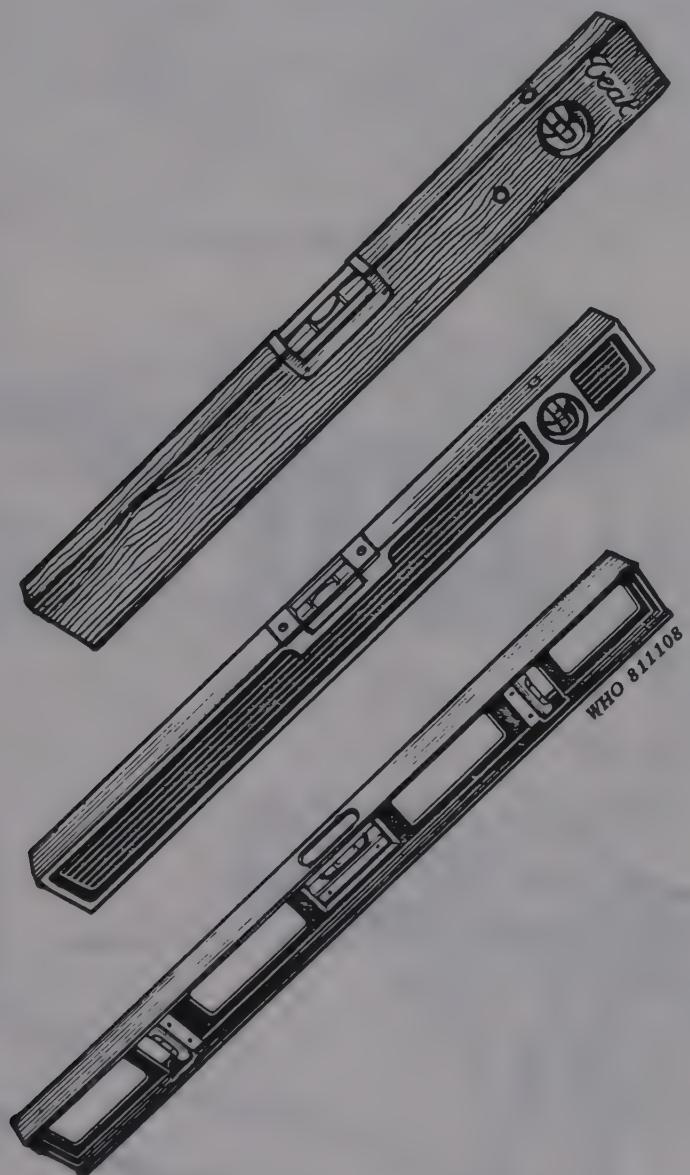


Fig. VII-18. Carpenter's levels

When using a carpenter's or a mason's level, apply a corner of the frame to the eye and use an upper edge as the line of sight. A small mirror may be attached to the top, at such a position and angle that it will show the reflection of the bubble when the eye is at the sighting point.

The other piece of simple equipment for topographic levelling is the graduated staff for measuring the differences in height of points on the ground and elsewhere, from the horizontal line of sight of the level. For small-scale work, measuring staffs can be replaced by straight pieces of wood of 4 x 4 cm section and 2.1-2.4 m in length. These home-made staffs are marked with bands of self-adhesive tape in two contrasting colours, one alternating with the other, to indicate 30 cm lengths in the staff. An ordinary plastic or wooden ruler 30 cm long, graduated in millimetres, is fixed to the staff by two rubber bands so that the zero mark of the ruler coincides with a division in the staff. The man who holds the staff vertically slides a finger along the ruler up or down, according to the instructions of the level-man, and reads the relevant figure on the ruler. With some practice it may be possible to take readings at distances of up to 50 m.

An alternative is to try to build and use a "water trough level" (see Fig. VII-19). A trough approximately 1 m long, 7.5 cm wide and 15 cm deep is made of wood or metal, and half filled with water. To its ends, inside it, are fastened vertically two straight lengths of wood, about 2.5 x 5 x 90 cm. These must be precisely the same length. The trough is placed upon any convenient base and wedged up to be horizontal. The depth of water is adjusted until its surface just touches the bottoms of both vertical lengths of wood. Since these are identical in length, and their bottom ends just touch the surface of the water in the trough, a line of sight over the top ends will be parallel to the surface of the water in the trough, and thus to the average surface of the earth at that point.

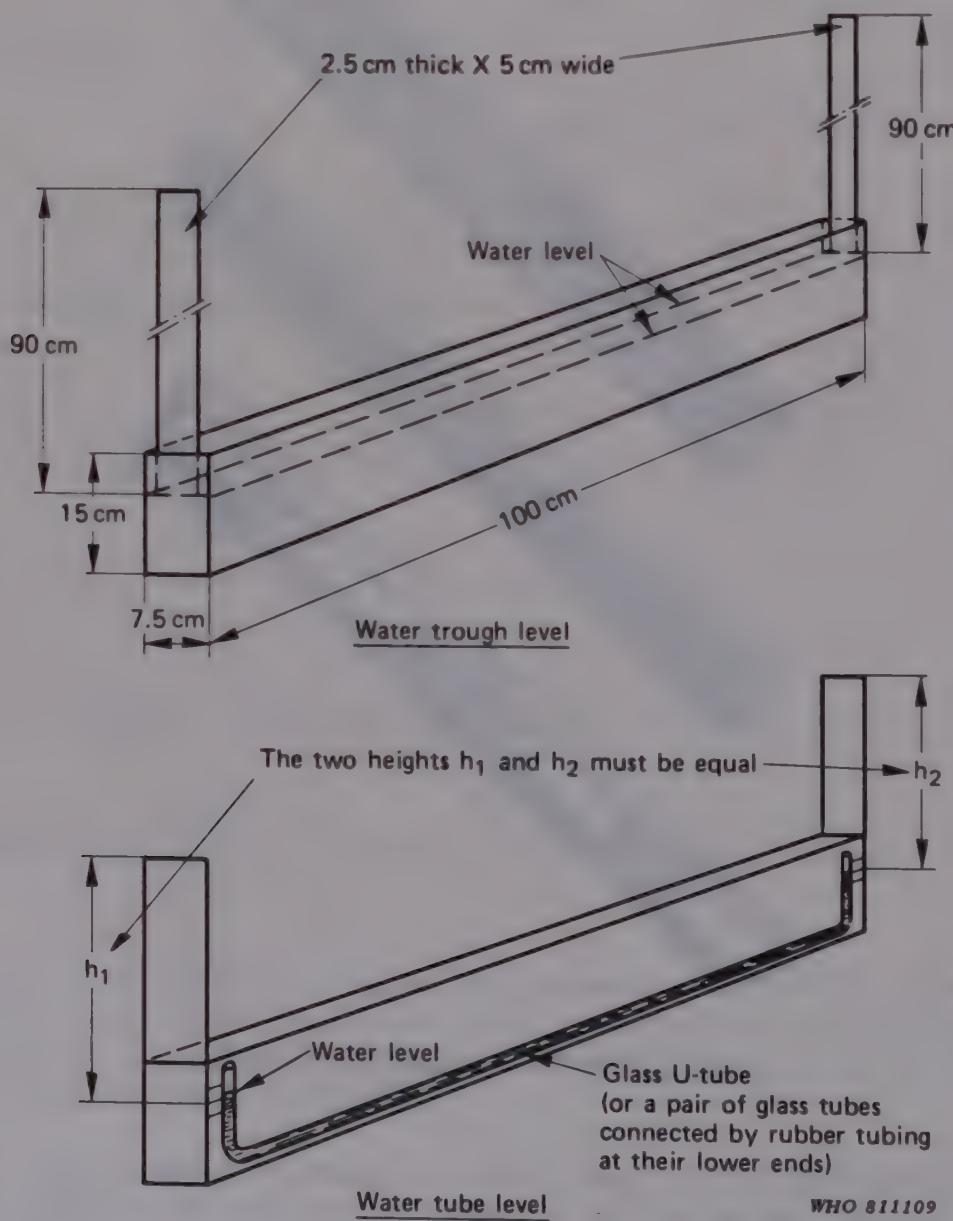


Fig. VII-19. Water trough and water tube levels

WHO 811109

Instead of the water trough, a U-tube or a pair of glass tubes connected by rubber tubing at their lower ends may be used and the water surface in the legs of the U-tube will define the horizontal. The levelling procedure, using a water trough level or a water U-tube level, would be much the same as that using a carpenter's level.

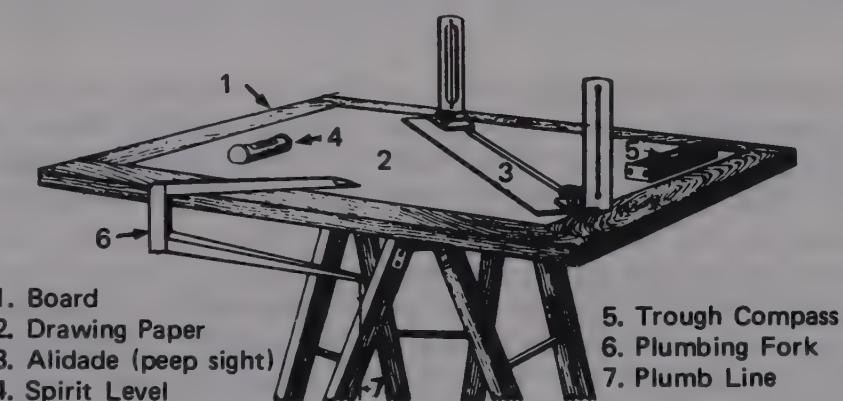
5.3 Plane-table surveying^a

5.3.1 Introduction

Plane-tableting is a method of surveying in which the field observations and plotting proceed simultaneously. It is simple because notes of measurements are not required, and it is particularly useful in open ground where sights are generally unobstructed.

5.3.2 The instrument

The plane-table consists of a drawing board (the table) which carries the sheet and is mounted on a tripod, a sight rule called the alidade, and several accessories including a spirit level, a plumbing fork, a plumb line and a compass. Two basic kinds of table are used: a small traverse table with peep-sight alidade and fixed-leg tripod without levelling head, obviously appropriate only for rough work; and the standard plane-table board, usually 60 x 80 cm, with telescopic alidade fixed with spirit levels, set on a tripod having a levelling head which can be levelled, rotated about a vertical axis, and clamped in any position (see Figs. VII-20 and VII-21).



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Fig. VII-20. Plane-table

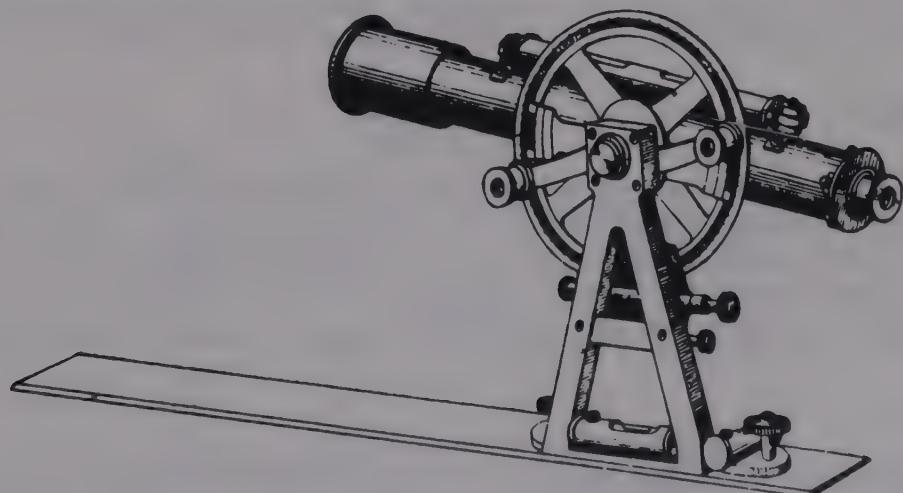


Fig. VII-21. Telescopic alidade

^a Clark, D. Plane and geodetic surveying for engineers. Vol. I: Plane surveying, London, Constable, 1937. Merritt, F.S. Standard handbook for civil engineers, New York, McGraw-Hill, 1968.

The various components of the plane-table instrument must be in correct adjustment as described below in order to ensure accuracy.

The board. The upper surface should be a perfect plane and should be perpendicular to the vertical axis of the instrument.

The alidade. The fiducial edge of the ruler should be a straight line. The alidade spirit levels should have their axes parallel to the base of the ruler. In the case of the peep-sight alidade, the sights should be perpendicular to the base of the ruler.

The telescope. The line of sight should be perpendicular to the horizontal axis of the telescope. The horizontal axis should be parallel to the base of the ruler. The axis of the telescope level should be parallel to the line of sight.

The index frame. The vertical circle should read zero when the line of sight is horizontal.

Procedures for testing and for the adjustment of the plane-table can be found in textbooks on plane surveying.

5.3.3 Methods of surveying with the plane-table

All surveys require some kind of control, be it a base line or bench mark, or both. Horizontal control consists of points whose positions are established by traverse or triangulation.

A traverse is a framework consisting of a series of connected lines, the lengths and directions of which are measured. When the lines form a circuit which ends at the starting-point, it is termed a closed traverse; otherwise it is unclosed. Except for very small jobs, it is usually advisable first to establish a traverse in plane-table surveying. It is with reference to those points on the traverse that field details are located and plotted. Procedures for the basic operations in plane-table surveying, including setting up the table, traversing, locating points by "radiation" and by "intersection", and measuring elevations, are described below; special problems in plane-table surveying such as the so-called "three-point problem", "two-point problem" and "method of resection" are not dealt with.

5.3.3.1 Setting up the table

In setting up the table at a station, three requirements have to be met: (a) the table must be levelled; (b) the table must be oriented; and (c) the point on the paper (representing the station being occupied) should be vertically over the point on the ground.

(a) Levelling the table

The legs should first be spread to bring the table approximately level and the board to a convenient height for working — preferably not above the elbow. The table is then placed over the station to fulfil requirements (b) and (c) approximately, and the levelling is completed by means of the levelling screws, by tilting the board by hand if the instrument has a ball and socket head, or simply by adjusting the legs if there is no levelling head.

(b) Orientation

The table is said to be oriented when it is so placed, with respect to its vertical axis, that all lines on the paper are parallel to the corresponding lines on the ground. Orientation, in this sense, is obviously not required at the first station.

The orienting is usually achieved by making use of a backsight. Thus, if the table be set over a station B, represented on the paper by a point b which has been plotted by means of a line ab drawn from a previous station A, the orientation will consist in bringing ba on

the paper over BA on the ground. The edge of the alidade is therefore placed along ba, and the board is turned in azimuth until the line of sight bisects the signal A, when the horizontal movement is clamped.

Orientation may also be effected (independently of a backsight) by the employment of the trough compass. At the first station, after the table has been levelled and clamped, the compass box is placed on the board — preferably outside the limits of plotting — so that the needle floats centrally, and a fine pencil line is ruled against the long side of the box. At any subsequent station the compass is placed against this line and the table is oriented by turning it until the needle again floats centrally. The accuracy of compass orientation is dependent upon the absence of local attraction, but is suitable for work in which speed is of greater importance than accuracy. The compass often proves a valuable adjunct in enabling a rapid approximate orientation to be made prior to the final adjustment, using a backsight.

(c) Centring

It has been assumed that b is set vertically over B by use of the plumbing fork and plumb line, so that ba is brought into the same vertical plane with BA. If b happened to lie in the vertical axis of the instrument, its position would be unaffected by the movement of the board in orienting, but otherwise b will be shifted relatively to the mark on the ground. The operations of orienting and centring are therefore interrelated and, if circumstances require that the plotted station point shall be exactly over the ground point, repeated orienting and shifting of the whole table are necessary. Commonly, however, accurate centring is a needless refinement because the error introduced by inexact centring is rather small.

5.3.3.2 Traversing

This method is used for laying down the survey lines of a closed or unclosed traverse. The detail may then be located by an appropriate method with reference to the points or lines on the traverse.

Having selected a system of stations A, B, C, D, and E (see Fig. VII-22), start by setting up over one of them (say A) and, having selected a on the paper, bring it over A. Clamp the board and, with the alidade touching a, sight E and B and draw rays ae and ab. Measure AE and AB and scale off ae and ab. Set up at B, with b over B, and orient by laying the alidade along ba, turning the table until the line of sight strikes A, and then clamping. With the ruler against b, sight C, and draw bc to scale. Proceed in this manner at the other stations, in each case orienting by a backsight before taking the forward sight.

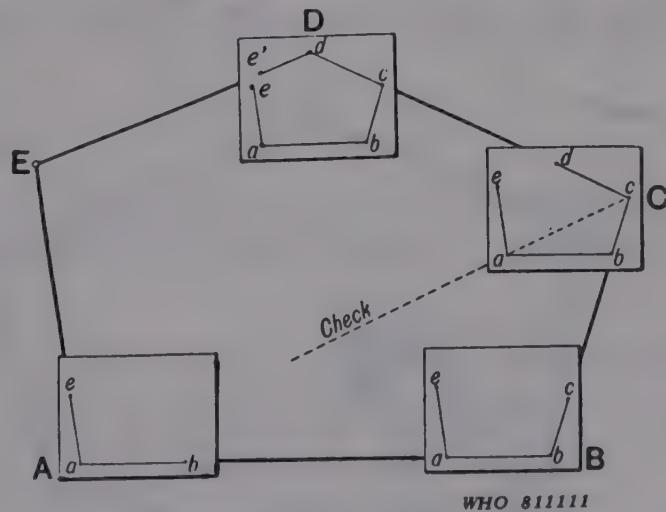


Fig. VII-22. Traversing.

Normally there is an error of closure at e which is determined at D (in the case described) and E need not be occupied. Intermediate checks should be taken whenever possible. Thus if A is visible from C , the work up to C may be checked there by sighting A with the ruler against c and noting if the edge touches a .

The error of closure can be adjusted graphically. In Fig. VII-23 the polygon $Abcdefa$, as plotted, is found to have a closing error aA . This error is distributed by shifting each plotted station in a direction parallel to that of aA and by an amount proportional to its distance along the traverse from the initial station A . The corrections may be obtained graphically as shown. $ABCDEFa$ is the adjusted traverse.

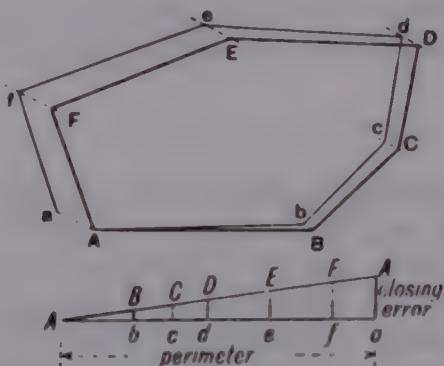


Fig. VII-23. Graphical adjustment of the error of closure.

5.3.3.3 Plotting the detail

(a) Locating points by radiation

Locating a point by radiation requires the measurement of a direction and a distance. As described in section 5.3.3.2 above, the manner of locating and plotting the stations (subsequent to the initial one) is in fact the application of the method of radiation.

The procedures for locating points by radiation are as follows: Set up and orient the table at a station (station A in Fig. VII-24) and clamp the horizontal movement. With the alidade touching a , sight the various points L , M , N , etc. to be located, drawing radial lines towards them. Measure distances AL , AM , AN , etc., set them off to scale, and join the points l , m , n , etc., so obtained.

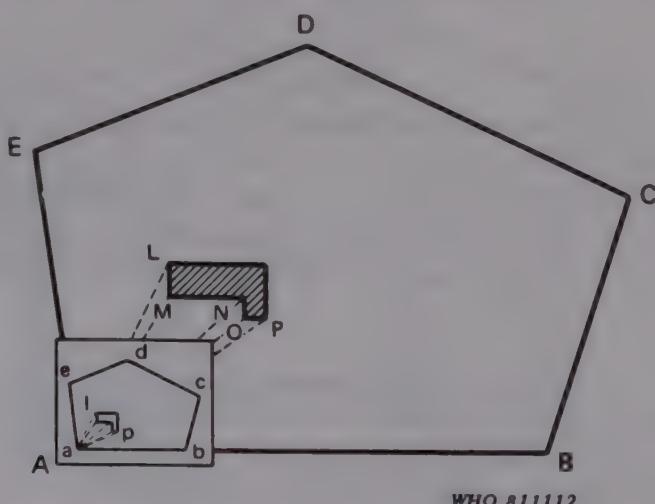


Fig. VII-24. Locating points by radiation.

(b) Locating points by intersection

This method is largely used for mapping detail but is also available for plotting the positions of points to be used as subsequent instrument stations. The only linear measurement required is that of a base line.

Lay out and measure a base line AB (Fig. VII-25). Plot ab in a convenient position on the sheet. Set up at A with a over A, and orient by laying the alidade along ab and turning the table until the line of sight cuts B. Clamp, and, with the ruler touching a, sight the various points defining the surrounding detail and points selected as future instrument stations, drawing a ray from a towards each. Proceed to B, set up with b over B, and orient by backsighting on A. Through b draw rays towards the points previously sighted. Each point is located by the intersection of the two rays drawn towards it. Before leaving B, draw a series of first rays towards other points not sighted from A, and then proceed to C, orient on A or B, and obtain a new series of intersections.

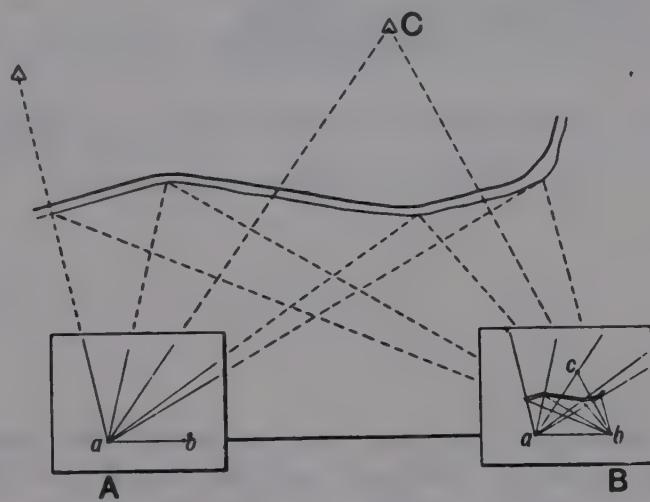


Fig. VII-25. Locating points by intersection.

An extended survey should, whenever possible, be based upon a system of points whose relative positions have been obtained by traversing. No base line is then required, and not only can such stations be occupied by the table but, on setting up at other sites, the orientation can be verified by reference to them and accumulation of error is avoided.

In order to yield definite intersections, it is desirable that intersection angles should not be less than 45° .

5.3.3.4 Measuring elevations

With a telescopic alidade, elevations of points can be determined by direct levelling or computed from vertical angles and scaled map distances. However, direct levelling using the alidade is slow.

The Indian clinometer, as shown in Fig. VII-26, is an instrument for measuring vertical distances and is specially suited to plane-tableing. The front sight vane is graduated in degrees and natural tangents, and the eyehole of the rear vane is horizontally opposite the zero of the scales when the instrument is levelled. The elevation of the station occupied can be determined by observation of a point of known level already plotted. The surveyor places the clinometer in the direction of the distant point, levels it, and, with the eye a few inches from the sighting hole, observes the graduation on the tangent scale opposite the point sighted. The difference of level is the tangent times the distance as scaled from the map, and to this result will be applied the height of the line of sight from the ground under the table.

The peep-sight alidade cannot be used for determining elevations.

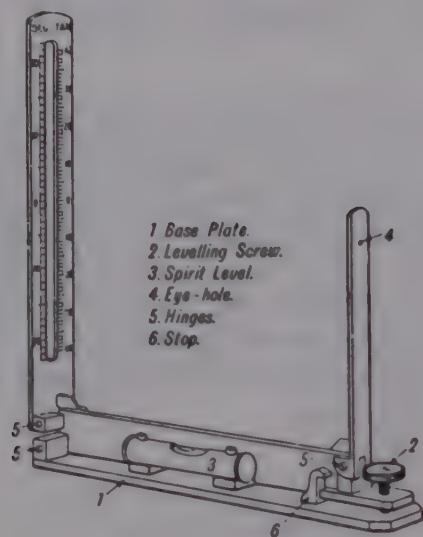


Fig. VII-26. Indian clinometer

5.3.4 Field party

5.3.4.1 Personnel

For small surveys, the surveyor does not require more than two men to measure distances, mark stations, etc. In large surveys, the work may be expedited if the surveyor has a qualified assistant who can proceed with the plotting while the chief reconnoitres the forward ground. The number of men required depends on the nature of the ground as well as the method of surveying. In tacheometrical radiation, it will usually be possible to keep two staffmen fully occupied, and more if the points sighted are widely spread.

5.3.4.2 Equipment

The amount of apparatus to be carried depends upon the nature and magnitude of the survey. A full equipment consists of:

Plane-table, tripod, and alidade.

Spirit level, trough compass, plumb-bob, fork and cover.

Scales, one or two set-squares, pencils, rubber, sand-paper, ink, colours, drawing pen, and small notebook.

Portfolio or cylindrical case for sheets.

Poles and flags.

For tacheometry: staff and stadia reduction tables or diagram.

For traversing, etc.: chain or tape, and pins.

For barometric levelling: aneroid.

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ANNEXES

CONTENTS

	<u>Page</u>
1. Basic information on mosquito vectors and diseases	227
A. Important malaria vectors	227
Table 1.1 Important malaria vectors	229
Table 1.2 Notes on the biology of the more important malaria vectors	231
Further reading list	237
B. Important vectors of lymphatic filariasis	241
Table 1.3 Filarial parasites transmitted by mosquitos	241
Table 1.4 Notes on the biology of important filarial vectors	242
Further reading list	244
C. Important mosquito vectors of arboviral diseases	247
Table 1.5 Important arboviral diseases transmitted by mosquitos	247
Table 1.6 Biology of important mosquito vectors of arboviral diseases	249
Further reading list	253
D. Pest mosquitos	255
Table 1.7 Important pest mosquitos	255
Table 1.8 Distribution and biology of important pest mosquitos	260
2. List of environmental management measures which have proved to be useful in the prevention and control of malaria and schistosomiasis	265
3. Matrix for the study and analysis of the environmental impact of a reservoir in a water resources development project	269
4. Checklist of major steps for the prevention and control of vector-borne diseases at each phase of water resources development projects	272
5. Equipment for environmental management	276

Annex 1

BASIC INFORMATION ON MOSQUITO VECTORS AND DISEASES

A. Important malaria vectors

The basic epidemiology of malaria involves a man-Anopheles-man transmission cycle. Usually transmission takes place indoors, the dangerous vector entering the houses at night to feed on man; it may also occur outdoors where people sleep or spend the evening hours outside their houses. Malaria epidemiology depends on environmental factors (climate, topography, hydrology, housing), on human factors (land use and occupation, daily activities and habits, migration of people, malaria prevalence), and on entomological factors (density, flight range, breeding, feeding and resting habits of mosquitos, and infection rate).

All mosquito larvae require water for their development and almost all sorts of water locations have been exploited by the several thousands of mosquito species. In the choice of breeding places, certain species are highly selective; other species are rather indifferent and their larvae may be found in a wide variety of water bodies. Despite many years of research there is still no clear understanding of the natural propensity of the female mosquito to select a particular type of water as being most suitable for oviposition.

Major factors that determine habitat preference are shade or sun exposure, quiet or flowing water, temperature, salt content, surface vegetation and floatage, and organic pollution. The following classification attempts to identify the most common breeding habitats and to indicate for each type the most suitable environmental management measures for its control.

A. Large bodies of fresh water in full or partial sunlight. Larvae occur in floating or emergent vegetation or floatage near the edges.

1. Impoundments, lakes, pools, bays, large borrow pits, slow rivers, and pools in drying beds of rivers and major streams.
2. Marshes, bogs, and swamps.

Control: Shoreline straightening by cutting, deepening and filling; shoreline preparation by levelling, grading and clearing vegetation; filling or draining side pockets; water level management; introduction of natural enemies and predators; drainage, filling, and ponding or canalizing of marshes and swamps.

B. Small collections of seepage water, stagnant and often muddy, but not polluted; full to partial sunlight. Vegetation present or absent.

1. Semipermanent rain pools or overflow water; roadside ditches, clogged drainage ditches, small borrow pits, wheel ruts, hoofprints, natural depressions on the ground, and puddles at the edge of ricefields.
2. Desert saline pools.

Control: Filling and grading; drainage.

C. Ricefields.

Control: Intermittent irrigation of paddy fields with flooding and drying periods; grading of paddies and ditches for rapid dewatering; vegetation clearance.

D. Brackish or saltwater marshes and lagoons; saltwater fish ponds; full or partial sunlight.

Control: Drainage, deepening and filling, ponding, canalizing, changing salinity by using tidegates and dikes, marshland reclamation, and vegetation clearance.

E. Partially or heavily shaded water in forests or jungles.

1. Pools, ponds, swamps, and sluggish streams.
2. Springs, shallow seepages and puddles on forest ground.

Control: Drainage, filling, ponding, canalizing, vegetation removal, and jungle clearance.

F. Running water courses, clear fresh water, direct sunlight.

1. Shallow gravelly stream beds with emergent grass and weeds.
2. Margins of foothill streams; small irrigation channels of upland ricefields.
3. Lowland grassy or weedy streams and irrigation ditches.
4. Stream bed pools and side pockets with abundant algae mats.
5. Pools in drying stream beds.
6. Rock holes in stream beds.

Control: Stream bed correction and clearance, channelling, ponding, sluicing and flushing, shading, and vegetation and debris clearance.

G. Springs; seepages from streams, irrigation channels and tanks; clear water; direct sunlight.

Control: Drainage, filling, repair of leaks in dams and embankments, and vegetation clearance.

H. Plant hollows and cavities: epiphytic arboreal and terrestrial bromeliads.

Control: Destruction of water-holding plants.

I. Man-made containers: wells, cisterns, water storage tanks, ornamental basins, tins, plastic packages, etc.

Control: Tight covers or screens for essential water storage cisterns, barrels, etc., and emptying, piercing or destroying unnecessary water containers.

Table 1.1 presents a list of the Anopheles mosquitos most commonly incriminated in malaria transmission and their chief preferences in breeding habitats; they are grouped according to geographical distribution. The symbols used for habitats agree with the above classification. A capital letter denotes a definite preference for such type of habitat; a small letter indicates that, to a lesser degree, larvae of the particular species are found in this type of habitat, either in the presence or absence of the preferred habitat.

Table 1.2 presents an alphabetical list of Anopheles species that are important in malaria transmission, with a summary of information on the adult mosquito habits and on larval habitats.

Table 1.1. Important malaria vectors

Region	<u>Anopheles</u> species	Habitat**
1. North America		
(a) Southeastern	<u>quadrimaculatus</u> Say	A1,2; b1
(b) Southwestern	<u>freeborni</u> Aitken	C; F3; G
(c) Mexico	<u>albimanus</u> Wiedemann <u>pseudopunctipennis</u> Theobald <u>aztecus</u> Hoffman	A1,2; B1; G F4 A1; E
2. Central America and West Indies	<u>albimanus</u> Wiedemann <u>aquasalis</u> Curry <u>pseudopunctipennis</u> <u>bellator</u> Dyar and Knab <u>punctimacula</u> Dyar and Knab	A1,2; B1; d D F4; g H E1
3. South America	<u>*darlingi</u> Root <u>*albimanus</u> Wiedemann (Ecuador), Colombia, Venezuela) <u>aquasalis</u> Curry <u>pseudopunctipennis</u> Theobald (Northern and Western) <u>*nuneztovari</u> Gabaldon (Northern) <u>albitarsis</u> Lynch Arribalzaga <u>punctimacula</u> Dyar and Knab <u>bellator</u> Dyar and Knab <u>cruzii</u> Dyar and Knab	E1; a1,2 A1,2; B1; d D F4; g A2 A1,2 E1 H H
4. North European and Asiatic regions	<u>labranchiae atroparvus</u> Van Thiel <u>maculipennis messeae</u> Falleroni <u>*sacharovi</u> Favre <u>sinensis</u> Wiedemann (Southern China) <u>pattoni</u> Christophers (Northern China)	D A1,2 D; a2 C; A1 F4,5

** See pages 227-228 for explanation of symbols.
* Species responsible for continuing transmission.

5. Mediterranean region	<i>*sacharovi</i> Favre <i>labranchiae labranchiae</i> Falleroni <i>l. atroparvus</i> Van Thiel (Spain, Portugal) <i>*superpictus</i> Grassi <i>claviger</i> Meigen <i>m. messeae</i> Falleroni <i>sergentii</i> Theobald <i>hispaniola</i> Theobald	D; a2 D; c D; c F1; f3; G B1; F5 A1,2 C; F3; b1; g A2; F4
6. Desert (North Africa and Arabia)	<i>*sergentii</i> Theobald <i>*pharoensis</i> Theobald <i>multicolor</i> Cambouliu <i>hispaniola</i> Theobald	C; F3; b1; g A2; c B1,2; i A2; F4
7. Ethiopian region (a) Africa	<i>dthali</i> Patton <i>pharoensis</i> Theobald <i>*gambiae</i> Giles <i>arabiensis</i> Patton <i>*melas</i> Theobald (West coast) <i>merus</i> Dönnitz (East coast) <i>*funestus</i> Giles <i>nili</i> Theobald <i>moucheti</i> Evans	F3; g; i A2; c B1 D D A1,2 F3 A2
(b) Yemen	<i>*gambiae</i> s.l. <i>culicifacies</i> Giles <i>sergentii</i> Theobald	B1 F4,5; B1; C; I C; F3; b1; g
8. Middle East and South-East Asia	<i>*culicifacies</i> Giles <i>*stephensi</i> Liston <i>minimus</i> Theobald <i>*fluviatilis</i> James <i>varuna</i> Iyengar <i>annularis</i> van der Wulp <i>philippinensis</i> Ludlow <i>*hyrcanus</i> Pallas <i>*pulcherimus</i> Theobald <i>*superpictus</i> Grassi <i>sundaicus</i> Rodenwaldt <i>dthali</i> Patton	F4,5; B1; C; I I; b1; f3,5 F2 F2; a2 F2 A1 A1,2; C C C F1; G; f3 D F3; g; i
9. Hill zones of Burma, Thailand and Indo- china	<i>*minimus</i> Theobald <i>*balabensis balabensis</i> Baisas <i>annularis</i> van der Wulp <i>maculatus</i> Theobald	F2 E2 A1 F2; g

10. South-East Asia region (Malaysia, Indonesia, Philippines, coastal plains from south China to Bengal)	<u>sundaicus</u> Rodenwaldt <u>letifer</u> Sandosham <u>umbrosus</u> Theobald *b. balabacensis Baisas <u>maculatus</u> Theobald <u>minimus</u> Theobald <u>minimus flavirostris</u> Ludlow (Philippines) <u>subpictus</u> Grassi <u>sinensis</u> Wiedemann <u>aconitus</u> Dönitz <u>campestris</u> Reid <u>donaldi</u> Reid <u>philippinensis</u> Ludlow <u>leucosphyrus</u> Dönitz	D E1 E1 E2 F2; g F2 F2 B1; C A1,2; c A1,2; C A2; c; f3 A2; C A1,2; C E1,2
11. Chinese region (Central China, Korean peninsula, Japan)	<u>sinensis</u> Wiedemann <u>pattoni</u> Christophers <u>lesteri</u> Baisas and Hu <u>martinius</u> Shingarev	A1,2; C F5,6 C D; a2
12. Southern & Western Pacific regions	*farauti Laveran *koliensis Owen *punctulatus Dönitz <u>bancrofti</u> Giles <u>subpictus</u> Grassi <u>karwari</u> James	B1 B1; d B1 F3 B1 B1; F3; a1; g

Table 1.2. Notes on the biology of the more important malaria vectors

Anopheles aconitus (Oriental region)

Adult habits: Zoophilic, but will bite man indoors and outdoors. Resting sites: houses, animal sheds, bushes, stream banks. Observed flight: 1 km.

Larval habitats: Ricefields, lakes, ponds, swamps, impoundments.

(continued overleaf)

An. albimanus (Mexico, Central and South America)

Adult habits: Zoophilic and moderately anthropophilic; a significant proportion of females enter houses to feed on man. Resting sites: houses, sheds, rockpiles and walls, bridge abutments, tree holes. Females active through evening hours. Observed flight: 2 km.

Larval habitats: Open, sunlit impoundments, lakes, ponds, marshes, swamps, pools; rain-filled small depressions, hoofprints, wheel ruts.

An. balabacensis (Malaysia, Indonesia, Thailand, Burma, India)

Adult habits: A shade-loving inhabitant of dense forest and forest fringes. Strongly anthropophilic; females bite people in or near forests, indoors and outdoors. Resting sites: shelters in forest, shrubs, stream banks; brief periods of resting in houses before and after feeding during the night. Flight range uncertain, but invades villages from a nearby forest.

Larval habitats: Deeply shaded pools and seepages in densely shaded rain forests; hoofprints, mining pits, irrigation ditches; also man-made excavations including those in open sun.

An. campestris (Malaysia, Thailand)

Adult habits: Strongly anthropophilic, bites man both indoors and outdoors; peak of activity from 20 00 to 02 00 hours.

Larval habitats: Ricefields, swamps, marshes, ponds, pools, ditches, canals, hoofprints.

An. culicifacies (Middle East, South-East Asia, China)

Adult habits: Recognized as the most important vector in the Indian region in spite of the high rate of adult mortality, because of its enormous population densities. Adults feed on man or domestic animals at night in houses or stables. Resting sites: houses, stables, sheds; dense vegetation. Observed flight: 1 km.

Larval habitats: Pools, borrow pits, drying stream beds, ponds, irrigation channels, rice-fields.

An. darlingi (S. America)

Adult habits: Strongly anthropophilic, endophilic, and endophagic, although in the interior of South America there are populations that can be caught in animal traps and which feed on animals and man out of doors. The peak of indoor biting activity occurs from 24 00 to 02 00 hours. Observed flight: 1.5 km.

Larval habitats: Large shaded reservoirs, ponds, irrigation canals, swamps, stream margins, ricefields, pools.

An. dthali (Middle East, India, and East, West and Central Africa)

Adult habits: A vector in Iran, where it bites man, and rests both indoors and outdoors. Also suspected to be a vector in northern Somalia.

Larval habitats: Wells, seepages, pools in river beds, grassy streams.

An. fluviatilis (Middle East, South-East Asia, China)

Adult habits: Anthropophilic and endophilic; enters houses at night to feed and rest. Gravid females have been observed to leave shelters at dusk to oviposit, and to return for another blood meal within an hour. Observed flight: 1 km.

Larval habitats: Hill streams, ditches, irrigation channels, spring pools, wells, ponds, ricefields.

An. funestus (Ethiopian region)

Adult habits: Strongly anthropophilic, endophagic, and endophilic. Prefers man even in the presence of sheep and cattle, although some animal feeding also occurs. Peak of indoor biting in second half of the night. Preferred resting sites are houses; some outdoor resting in tree buttresses, overhanging earth banks, rock crevices, etc. Observed flight: 7 km.

Larval habitats: Permanent, vegetated waters, including swamps, ponds, lake margins, streams, ditches; ricefields.

An. gambiae s.l. (Ethiopian region)

Adult habits: Six species are now recognized in the An. gambiae complex. An. gambiae and An. arabiensis, the principal malaria vectors in tropical Africa, are strongly anthropophilic, endophagic, and endophilic; however, outdoor feeding and resting also occur. An. quadriannulatus appears to be entirely exophilic and zoophilic. A. melas is a vector which is abundant near salt-water breeding places on the west coast. A. merus is a vector in East, Central and Southern Africa and breeds in saline and brackish water extending well inland. Species D, the sixth member of the An. gambiae complex, is not a vector. It breeds in mineral water springs and has been found only in a forest in Uganda.

Larval habitats: All kinds of water-filled depressions in the ground, especially shallow sunlit pools, borrow pits, hoofprints, wheel ruts, and pits from which soil for mud bricks was excavated. A. merus and A. melas breed in brackish and saltwater marshes and lagoons along the east and west African coasts respectively.

An. hyrcanus (Central and Northern Asia, Japan, Hungary, and Mediterranean region)

Adult habits: The type form has been shown to be a vector in north-east Afghanistan; here adults do not rest in houses because of low humidity, but do rest on outside walls of houses, in caves, hollow trees, creek banks, and vegetation. They become active shortly after sunset, and then attack people in gardens and fields. They do not bite indoors.

Larval habitats: Ricefields, ponds, swamps.

An. lesteri (Western Pacific, China)

Adult habits: Said to be the primary malaria vector in the Changjiang (Yangtze) valley; strongly anthropophilic here.

Larval habitats: Ricefields, ponds, swamps, lakes.

An. letifer (Indonesia, Malaysia, Thailand)

Adult habits: In partially cleared or more open forests of coastal Malaysia; females enter houses at night to feed on man; also attack by day in the shade.

Larval habitats: Shaded or partly sunlit pools, drains, especially with accumulations of decaying leaves and other vegetation.

An. leucosphyrus (South-East Asia)

Adult habits: Shown to be a vector in northern Sarawak; here adults enter houses to feed on people, with peak activity between 12 00 and 02 00 hours.

Larval habitats: A forest species; breeds especially in seepages and rain pools.

An. maculatus (Oriental region)

Adult habits: A vector in the foothills of Malaysia, especially following deforestation. Prefers cattle, but readily attacks man both indoors and outdoors. Most biting activity between 21 00 and 24 00 hours; most females leave houses before 08 00 hours. Observed flight: 2 km.

Larval habitats: Small, sunlit stream margins, seepages, springs, ricefields with running water.

An. minimus (Oriental region)

Adult habits: In foothills of India, minimus, fluviatilis, and varuna formerly were responsible for intense malaria transmission. An. minimus is of importance in Vietnam and elsewhere in South-East Asia, especially when forests are cleared in hilly regions. Adults feed on man both indoors and outdoors; biting activity occurs during the early part of the night.

Larval habitats: The edges of gently moving, clean, clear streams.

An. minimus flavirostris (Philippines, Indonesia)

Adult habits: The vector in foothill regions. Adults enter houses to feed on man, but leave early in the morning so that they are seldom found in house catches. Resting adults may be taken from overhanging creek banks and similar outdoor shelters. Commonly taken in animal-baited traps. Observed flight: 2 km.

Larval habitats: Margins of small, sunlit streams.

An. moucheti (Central Africa)

Adult habits: Strongly anthropophilic, endophagic, endophilic; also attacks man outdoors. Biting activity continues throughout the night.

Larval habitats: Ponds, pools, sluggish streams and large rivers in forested areas, especially with Pistia and other horizontal vegetation.

An. nili (Ethiopian region)

Adult habits: Anthropophilic, endophilic, and endophagic in some areas; less so in others.

Larval habitats: Shaded streams and river margins with surface vegetation; swamps, pits.

An. nuneztovari (South America)

Adult habits: Two populations may represent sibling species. One bites at sunset, feeds on man and animals mainly outdoors, and is not a vector. The other population (in northern Colombia and western Venezuela) is anthropophilic and endophagic, with peak activity between 22 00 and 24 00 hours.

Larval habitats: Pools, puddles, ponds, small lagoons, streams, ricefields.

An. pharoensis (Ethiopian region, North Africa, Middle East)

Adult habits: Secondary vector associated with malaria in Egypt. Adults bite man or animals indoors and outdoors, seldom rest in houses, but are found on reeds and other vegetation of the breeding places. Observed flight: 9 km.

Larval habitats: Ricefields, swamps, lakes, reservoirs.

An. pseudopunctipennis (Central and South America)

Adult habits: Formerly of importance locally; weakly anthropophilic. Females feed freely during the evening and night, out of doors on animals and man, and seek shelter at dawn in houses as well as elsewhere; at dusk both unfed and fully gravid females become active and leave the shelter. Observed flight: 6 km.

Larval habitats: Pools in drying stream beds with Spirogyra and other surface vegetation.

An. pulcherrimus (Middle East, South-East Asia)

Adult habits: Responsible, with hyrcanus, for continuing malaria transmission in Afghanistan. Adults feed outdoors on man and animals from sunset through the early part of the night. Outdoor resting sites are those shared with hyrcanus, but pulcherrimus also rests inside sheds and houses.

Larval habitats: Ricefields, swamps, ponds.

An. punctulatus group (Southern and Western Pacific regions)

Adult habits: Three species: punctulatus, faranti, koliensis, with similar behaviour patterns: homophilic, endophilic, and endophagic. Observed flight: 1 km.

Larval habitats: Rain pools, ruts, hoofprints, pools in drying stream beds; ponds, lagoons, seepages, swamps.

An. sacharovi (Mediterranean, Middle East)

Adult habits: Anthropophilic and zoophilic; endophagic and exophagic; endophilic and exophilic. Biting of people sleeping outdoors has contributed to the persistence of malaria in some areas. Observed flight: 8-14 km.

Larval habitats: Brackish water, coastal marshes, lagoons, pools; freshwater inland swamps and pools.

An. serpentii (Mediterranean, Middle East, South-East Asia)

Adult habits: Typically a desert species; a vector in oases. Adults bite man and animals indoors and outdoors, and rest in houses, sheds, caves, rockpiles, and crevices in the ground. Observed flight: 4 km.

Larval habitats: Streams, seepages, irrigation ditches, ricefields, borrow pits.

An. stephensi (Middle East, South and South-East Asia, China)

Adult habits: A dangerous vector throughout its range; anthropophilic, endophilic, endophagic. Especially adaptable to urban environments and so intensely domestic. Observed flight: 2.5 km.

Larval habitats: Stream margins, seepages, marshy areas, springs, ponds, pools, irrigation channels; wells, cisterns, and other artificial containers.

An. subpictus (South and South-East Asia, China, and South-West Pacific)

Adult habits: Widespread and common in South-East Asia. Considered to be an important vector in Timor; vector role elsewhere uncertain. Adults will feed and rest in houses, but prefer domestic animals. Observed flight: 1.5-6.2 km.

Larval habitats: Fresh and brackish water pools.

An. sundaicus (South-East Asia, China)

Adult habits: An important vector along the sea-coasts of South-East Asia and Indonesia. Highly anthropophilic; bites man indoors or outdoors, with peak activity between 22 00 and 24 00 hours. Resting sites: houses, stables; rock crevices, crevices in sand banks, bushes. Observed flight: 0.5-6.2 km.

Larval habitats: Brackish water marshes, lagoons, pools; salt-water fish ponds.

An. superpictus (Mediterranean, Middle East, Central Asia)

Adult habits: Responsible for continued malaria transmission in some localities of the Middle-East. Adults feed on man indoors and outdoors, and rest in houses, sheds, caves, earth crevices, and under bridges. Observed flight: 2-7 km.

Larval habitats: Shallow, grassy, pebbly streams, pools, seepages.

An. varuna (India, Sri Lanka, Burma, Nepal)

Adult habits: Formerly a dangerous vector in the hills of Bengal.

Larval habitats: Irrigation channels, seepages, wells.

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B. Important vectors of lymphatic filariasis

In general, the basic epidemiology of filariasis involves a man-vector-man transmission cycle. However, the transmission of Brugia malayi filariasis (subperiodic form) may involve animal hosts or reservoirs such as domestic and wild cats, civets and pangolins; infection is transmitted from animal to animal or man, and from man to man or animal by certain species of Mansonia mosquitos.

A wide range of mosquitos, including several species of Anopheles of malaria importance, are vectors of the various forms of filariasis. This gives a universal character to the disease transmission; it can occur at any time of the day or night, indoors and outdoors, near or away from human centres. Larval habitats are also most diverse; depending on the species involved, breeding takes place in salt, brackish and fresh water, either clear or polluted, in large water bodies, tidal lagoons, marshes, ponds, or in water contained in leaf axils, tree holes, coconut husks, barrels, tins, etc.

In regions where different vector species are responsible for filariasis transmission, such as the Malaysian and Australasian regions, vector control becomes an extensive and expensive operation.

Table 1.3 presents a list of filarial parasites, their distribution in geographical regions and preferred types of environment, summary notes on the disease epidemiology and the mosquito species most commonly involved in the transmission.

Table 1.4 presents a list of the important mosquito vectors of filariasis in alphabetical order, with summary information on adult habits and larval habitats.

Table 1.3. Filarial parasites transmitted by mosquitos

Parasite and distribution	Epidemiology	Important vectors
<u>Wuchereria bancrofti</u> periodic form, throughout the tropics (except Polynesia), some subtropical areas.	Man-mosquito-man transmission cycle. Principal vectors enter houses at night to feed on man. In rural areas these are <u>Anopheles</u> species; in the forests and plantations of S.E. Asia, forest-dwelling species of <u>Aedes</u> (<u>Finlaya</u>) may be of local importance; in urban areas the chief vector is <u>Culex quinquefasciatus</u> Say.	<u>Anopheles gambiae</u> <u>An. funestus</u> <u>An. darlingi</u> <u>An. minimus flavirostris</u> <u>An. campestris</u> <u>An. punctulatus</u> group <u>Aedes (F.) niveus</u> <u>Ae. (F.) kochi</u> <u>Ae. (F.) poecilius</u> <u>Culex quinquefasciatus</u> Say (= <u>Cx. pipiens fatigans</u> Wiedemann)
<u>W. bancrofti</u> diurnally subperiodic form, in Polynesia and New Caledonia; nocturnally subperiodic form, in Thailand.	Associated especially with coconut plantations, where the principal vector, <u>Ae. polynesiensis</u> , feeds by day on people working in these plantations or living in nearby houses. Locally, other species may transmit away from coconut plantations (see notes on vector biology, Table 1.6).	<u>Ae. (S.) polynesiensis</u> <u>Ae. (S.) tongae</u> <u>Ae. (S.) pseudoscutellaris</u> <u>Ae. (F.) fijiensis</u> <u>Ae. (O.) vigilax</u>

<u>Brugia malayi</u> nocturnally subperiodic form, swamp forests of Malaysia and the Philippines (Palawan, Sulu, Mindanao).	In addition to man, macaques and leaf monkeys, domestic and wild cats, civet cats and pangolins are subject to infection. Transmission from man to man, or animal to man, or man to animal, by swamp forest-dwelling species of <u>Mansonia</u> . Thus transmission takes place mostly in the swamp forest or in nearby villages by mosquitos which bite by day or night, indoors or outdoors, with the peak of activity during the evening.	<u>Mansonia dives</u> <u>Ma. bonneae</u> <u>Ma. annulata</u> <u>Ma. uniformis</u>
<u>Brugia malayi</u> nocturnally periodic form, in Japan, coastal China, Korean peninsula, South-East Asia, India; nocturnally subperiodic form, in western Malaysia.	Man apparently is the only natural vertebrate host, and transmission takes place primarily in the domestic environment by night-biting mosquitos, either indoors or outdoors. Endemic foci of S. Asia usually associated with flat, swampy land. In Japan, <u>togoi</u> -transmitted foci are in communities near coastal salt-water rock pools and cisterns.	<u>Ma. annulifera</u> <u>Ma. indiana</u> <u>Ma. uniformis</u> <u>Ae. (F.) togoi</u> <u>An. campestris</u> <u>An. donaldi</u>
<u>Brugia timori</u> nocturnally periodic, in Indonesia.	Vertebrates such as monkeys, domestic and wild cats, civets and pangolins are included in the developmental cycle, as well as man.	<u>An. barbirostris</u>

Table 1.4. Notes on the biology of important filarial vectors

Species and distribution	Adult habits	Larval habitats
<u>Aedes (F.) fijiensis</u> Fiji Islands	Found naturally infected in Fiji. Persistent night-time biter.	Leaf axils of <u>Pandanus</u> and of some other plants
<u>Ae. (F.) kochi</u> Australian region	Bites man by day and night, indoors and outdoors; especially abundant in and near <u>Pandanus</u> groves.	Leaf axils of <u>Pandanus</u> , <u>Colocasia</u> , banana

<u>Ae. (F.) niveus</u> Philippines, Malaysia, Indonesia	Probable vector in forests.	Tree holes, bamboo stumps
<u>Ae. (F.) poecilius</u> Malaysia, Indonesia	Bites by day or night, indoors and outdoors; especially abundant in or near extensive abaca plantations in the Philippines.	Leaf axils of abaca, banana, <u>Pandanus</u>
<u>Ae. (F.) togoi</u> China (incl. Prov. of Taiwan), Japan, and Korean peninsula	Adults enter houses to feed on man.	Salt-water rock pools along the coast, artificial containers
<u>Ae. (O.) vigilax</u> Australian region, South-East Asia	Bites by day or night, indoors and outdoors. Vector of subperiodic <u>W. bancrofti</u> in New Caledonia. Observed flight: 96 km.	Brackish-water marshes and pools; fresh-water swamps and pools
<u>Ae. (S.) polynesiensis</u> Polynesia	Bites man by day in coconut groves, wooded areas, gardens, yards; and will also enter houses to feed. Flight limited.	Coconut half-shells discarded after removal of copra, rat-opened coconuts, tree holes, palm bracts, crab holes, barrels, tins, and other artificial containers
<u>Ae. (S.) pseudoscutellaris</u> Fiji Islands	Similar to those of <u>Ae. polynesiensis</u>	Similar to those of <u>Ae. polynesiensis</u>
<u>Ae. (S.) tongae</u> Tonga Islands	Bites outdoors by day in groves and plantations. Flight limited.	Coconut husks, tree holes, artificial containers
<u>Anopheles campestris</u> Thailand, Malaysia	Anthropophilic, endophilic.	Ricefields, marshes, ponds, ditches, pools
<u>An. darlingi</u>	(See Table 1.2.).	(See Table 1.2.)
<u>An. funestus</u>	"	"
<u>An. gambiae</u>	"	"
<u>An. minimus flavirostris</u>	"	"
<u>An. punctulatus</u>	"	"
<u>An. donaldi</u> Malaysia, Thailand	Bites man indoors at night and outdoors by day in the shade of the forest; also attracted to animals.	Ricefields, shaded swamps, drains, forest pools

<u>Culex quinquefasciatus</u> (<i>fatigans</i>) Worldwide in tropics and subtropics	Strongly domestic; bites man by night indoors and outdoors; rests by day in dark corners of bedrooms, sheds, culverts, etc. Observed flight: up to 11 km.	Especially polluted waters of drains, ponds, stagnant streams, pools; also tanks, barrels, tins, and other artificial containers
<u>Mansonia annulata</u> Malaysia, Indonesia, Philippines	Bites man by day or night, indoors and outdoors.	Swamp forests
<u>Ma. annulifera</u> South-East Asia	Enters houses at night to feed on man.	Open swamps, marshes, ponds; associated especially with <u>Pistia</u>
<u>Ma. bonneae</u> Philippines, Malaysia, Thailand	Bites man by day or night, indoors and outdoors; especially troublesome by day in the shade of the forest.	Swamp forests
<u>Ma. dives</u> Malaysia, South Pacific, Indonesia, India	Strongly anthropophilic; enters houses to bite man at night; attacks avidly by day in the shade of the forest.	Swamp forests
<u>Ma. indiana</u> Malaysia, Indonesia, India	Bites man indoors and outdoors, by night or day. Capable of long flights of several miles.	Open swamps, marshes, ponds
<u>Ma. uniformis</u> Worldwide in tropics	Bites man by day or night, indoors and outdoors. Capable of long flights of 32 km or more.	Swamps, pools, marshes; associated with <u>Pistia</u> , water hyacinth and swamp grasses

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C. Important mosquito vectors of arboviral diseases

The basic epidemiology of viral diseases transmitted by mosquitos involves a cycle in which animals usually play a major role as hosts and reservoirs. In fact, many viral diseases are originally zoonotic and only incidentally or sporadically are first transmitted to man. For instance, monkeys are the primary hosts of yellow fever and the Haemagogus mosquito, which is not anthropophilic, is a major monkey-to-monkey vector. However, if a monkey host is bitten by a suitable Aedes species, such as Ae. aegypti, Ae. africanus or Ae. simpsoni, the mosquito is able to transmit the virus to man, who becomes a host. Subsequent transmission, in a man-Aedes-man cycle, may be so intensive as to cause epidemic outbreaks among urban populations.

Other animals besides primates act as hosts or reservoirs for the arboviruses. They include wild and domestic fowl, equines, pigs, sheep and rodents.

Table 1.5 presents a list of the more important viral diseases transmitted by mosquitos, their distribution in geographical regions, summary notes on their epidemiology, and the most common vector species involved in the transmission.

Table 1.6 presents a list of the important mosquito species (in alphabetical order) with summary information on adult habits and larval habitats.

Table 1.5. Important arboviral diseases transmitted by mosquitos

Disease and distribution	Epidemiology	Vector
Yellow fever tropics and subtropics, Central and South America, and Africa	In South and Central America, the disease is enzootic in jungle monkeys and transmitted by <u>Haemagogus</u> spp. In periurban and urban areas, <u>Ae. aegypti</u> acts as the principal vector and is responsible for epidemics in these situations. In Africa, monkey-to-monkey transmission in forest areas is maintained by <u>Ae. africanus</u> , with <u>Ae. simpsoni</u> breeding in the plantain and banana plantations at the periphery of the forest, and acting as vectors between monkey and man. Periurban and urban transmission by <u>Ae. aegypti</u> can reach epidemic proportions.	<u>Aedes aegypti</u> <u>Ae. africanus</u> <u>Ae. simpsoni</u> <u>Haemagogus spegazzini</u> <u>Ae. leucocelaenus</u> <u>Sabettus chloropterus</u>
Dengue tropico- and subtropicopolitan	Explosive urban epidemics; endemic survival in tropical cities; diffuse endemicity in rural areas of S.E. Asia and Oceania.	<u>Ae. aegypti</u> <u>Ae. albopictus</u> <u>Ae. scutellaris</u> <u>Ae. polynesiensis</u>

Chikungunya fever East and South Africa, and S.E. Asia	Africa: sylvan cycle in monkeys, baboons, and <u>Ae. africanus</u> ; out- breaks with man- <u>aegypti</u> -man cycle in villages. S.E. Asia: urban outbreaks with man- <u>aegypti</u> -man cycle; possible supple- mental transmission by <u>Ae. albopictus</u> ; possible animal reservoirs.	<u>Ae. aegypti</u> <u>Ae. albopictus</u> <u>Ae. africanus</u> <u>Ae. taylori</u> <u>Ae. furcifer</u>
Western equine encephalitis North America	Basic cycle: bird-vector-bird- vector< (man) (equines) Reservoir in many species of wild birds; amplification of the virus in birds during the nesting season; transmission to man and equines in summer and autumn by <u>Cx. tarsalis</u> in western USA; enzootic foci in swamps in eastern USA; transmission by <u>Cs. melanura</u> . Man and equines are incidental hosts.	<u>Culex tarsalis</u> <u>Culiseta melanura</u>
Eastern equine encephalitis Eastern USA, Caribbean, and Central and South America	Basic cycle: bird-vector-bird- vector< (man) (equines) Enzootic swamp foci with wild birds as reservoirs; transmitted by <u>Cs. melanura</u> ; spillover to peri- domestic and domestic birds; sporadic transmission to man and equines in or near swamp foci by <u>Cs. melanura</u> ; outbreaks in man and equines with <u>Ae. sollicitans</u> as the chief vector.	<u>Cs. melanura</u> <u>Ae. sollicitans</u>
St. Louis encephalitis USA, and Central and South America	Basic cycle: bird-vector-bird-(man). Rural epidemiology in western USA, with <u>Cx. tarsalis</u> as the chief vector; urban epidemiology in central and eastern USA, enzootic cycles in woods- inhabiting birds; transmission among peridomestic birds and domestic fowls and to man by domestic mosquitos.	<u>Cx. nigripalpus</u> <u>Cx. pipiens</u> <u>Cx. quinquefasciatus</u> Say (= <u>Cx. p. fatigans</u> Wiedemann) <u>Cx. coronator</u> <u>Cx. tarsalis</u> <u>Psorophora ferox</u> <u>Sabettus chloropterus</u>
Venezuelan encephalitis Southern USA, and Central and South America	Basic cycle: mammal-vector-mammal- vector-(man) Reservoir in forest rodents, epi- zootics among equines with equines as a source of virus for the vector; infection of man during equine epi- zootics.	<u>Cx. taeniopus</u> <u>Ae. serratus</u> <u>Ae. taeniorhynchus</u> <u>Ps. ferox</u> <u>Ps. confinnis</u> <u>Mansonia titillans</u>

Japanese encephalitis Siberia to India	Basic cycle: pig-vector-pig-vector < (man) bird-vector (horses) Vertebrate hosts: heron, egrets, other birds; pigs, horses. Extensive out- breaks in man from time to time.	<u>Cx tritaenio-</u> <u>rhynchos</u> <u>Cx vishnui</u> <u>Cx gelidus</u> <u>Cx annulus</u>
West Nile fever Africa to India	Basic cycle: bird-vector-bird-(man). Reservoir in birds; man incidentally infected.	<u>Cx univittatus</u> <u>Cx antennatus</u>
Wesselsbron fever Africa and Thailand	Basic cycle: transmission among sheep and other domestic animals by mosquitos; occasional transmission to man.	<u>Aedes (B.) circum-</u> <u>luteolus</u> <u>Ae. (O.) caballus</u>
California encephalitis N. America	Basic cycle: vertebrate-vector-vertebrate vector - vector vector - (man). Reservoir hosts: hares, rabbits, ground squirrels, chipmunks; incidental infec- tion in man. Generation-to-generation survival of virus in mosquitos.	<u>Ae. canadensis</u> <u>Ae. trivittatus</u> <u>Ae. atlanticus</u>
Murray Valley encephalitis Australia, New Guinea	Basic cycle: bird-vector-bird-(man). Reservoir in birds; man incidentally infected.	<u>Cx annulirostris</u>
Rift Valley fever South, Central and West Africa, and Egypt	Basic cycle: domestic animals-vector- domestic animals-(man). Extensive outbreaks in man from time to time.	<u>Mansonia spp.</u> <u>Cx univittatus</u> <u>Cx pipiens</u> <u>Cx theileri</u>

Table 1.6. Biology of important mosquito vectors of arboviral diseases

Species and distribution	Adult habits	Larval habitats
<u>Aedes aegypti</u> feral strain: Africa domestic strain: tropico- and subtropicopolitan	Rests and bites outdoors in African bush. Rests and bites indoors; intimate association with man. Flight limited.	Tree holes and other plant cavities Artificial containers - tins, tubs, etc. in and near houses

<u>Ae. africanus</u> and <u>Ae. luteocephalus</u> Ethiopian region	Feeds on monkeys in forest canopy at night.	Rot holes in trees, bamboo stumps
<u>Ae. albopictus</u> Oriental and Australian regions, Djibouti, Madagascar, Seychelles and Mauritius	Annoying bites by day in coconut groves, bamboo thickets, outdoors near dwellings; also inside dwellings in some areas. Flight limited.	Plant cavities, especially coconut half-shells and rat-opened coconuts, bamboo stumps; tubs, tins, and other artificial containers near houses
<u>Ae. atlanticus</u> Eastern USA	Attacks man and animals in woods by day.	Temporary rain and flood pools
<u>Ae. caballus</u> Ethiopian region	Zoophilic, exophagic.	Rain and overflow pools, rock pools in stream beds
<u>Ae. canadensis</u> N. America	Attacks man and animals in woods by day.	Temporary rain and flood pools
<u>Ae. circumluteolus</u> Ethiopian region	Feeds on mammals in woods and fields with scrub vegetation.	Swamps, rain pools
<u>Ae. leucocelaenus</u> S. America	A forest mosquito, biting man and animals in the canopy but also at ground level. Flight limited.	Tree holes
<u>Ae. lineatopennis</u> Oriental, Ethiopian, and Australian regions	Zoophilic, exophagic.	Swamps, rain pools
<u>Ae. polynesiensis</u> Polynesia	Annoying bites by day in coconut groves, woods, yards, and also in houses. Flight limited.	Plant cavities, especially coconut half-shells and rat-opened coconuts; tree holes, palm spathes, artificial containers, crab holes
<u>Ae. serratus</u> North, Central, and South America	Bites man and animals by day or night, especially in woods. Observed flight: 1 km.	Temporary rain pools
<u>Ae. scutellaris</u> Indonesia, Melanesia, Philippines, Palau and Caroline Islands	Annoying biter by day in woods, coconut groves, yards, houses. Flight limited.	Plant containers, tree holes, coconut husks, artificial containers
<u>Ae. simpsoni</u> Ethiopian region	Attacks man and animals by day in and near banana and other plantations. Flight limited.	Leaf axils of taro, banana, plantain, and pineapple; other plant cavities

<u>Ae. sollicitans</u> Eastern USA and Greater Antilles	Vicious biter of man and animals by day or night. Capable of long flights, over 100 km.	Coastal salt marshes, inland salt pools
<u>Ae. taeniorhynchus</u> North, Central, and South America	Females attack man and animals by day or night; capable of long flights, over 35 km.	Coastal salt marshes
<u>Ae. trivittatus</u> N. America	Attacks man and animals by day in open woods and fields. Observed flight: 2.5 km.	Temporary rain and flood pools
<u>Culex annulus</u> Malaysia	Strongly attracted to pigs but will bite man.	Ricefields, ponds, brackish water pools, artificial containers
<u>Cx antennatus</u> Mediterranean and Ethiopian regions	Feeds on man and domestic animals.	Swamps, borrow pits, pools, ditches
<u>Cx coronator</u> North, Central, and South America	Feeds outdoors on avian and mammalian hosts.	Ground pools, seepages, hoofprints, tree holes, artificial containers
<u>Cx gelidus</u> Malaysia, China, Japan and India	Enters houses to feed on man; especially attracted to pigs.	Ricefields, marshes, ponds, pools, streams
<u>Cx nigripalpus</u> North, Central, and South America	Females feed on avian and mammalian hosts, including man.	Pools, ditches, marshes, swamps
<u>Cx pipiens</u> Holarctic region	Females feed on avian and mam- malian hosts; a troublesome night-time biter, both indoors and outdoors. Flight ordinarily limited, but over 20 km observed.	Contaminated or fresh-water ground pools, ditches, cesspools, artificial containers
<u>Cx quinquefasciatus</u> (<u>fatigans</u>) Tropico- and subtropicopolitan	Similar to those of <u>Cx pipiens</u>	Similar to those of <u>Cx pipiens</u>
<u>Cx taeniopus</u> Central and South America	Presumably feeds in forests, primarily on rodents.	Forest rain and stream pools

Cx tarsalis
N. America

In some situations, females prefer avian hosts, especially doves and pigeons; but in others, they feed primarily on animals especially cattle. They also bite man. Observed flight: 1.6-4 km.

Grassy, sunlit pools; irrigation ditches, seepages, marshes, hoof-prints; clear or polluted water

Cx tritaeniorhynchus
Oriental region and Africa

Bites man and animals by night, indoors and outdoors; especially attracted to pigs. Blooded adults rest in animal shelters by day.

Ricefields, marshes, ponds, pools, ditches, streams; cesspools

Cx univittatus
Mediterranean and Ethiopian regions, Middle East and India

Ornithophilic but in some areas feeds readily on man and domestic animals.

Marshes, pools, grassy streams

Cx vishnui
Oriental region

Bites man at night; also strongly attracted to cattle and pigs; also feeds on birds.

Ricefields, pools, ditches, swamps, rain pools

Culiseta melanura
Eastern and Central USA

Females feed by preference on swamp-inhabiting birds but also attack domestic and wild animals, reptiles, and occasionally man.

Swamps, bogs

Haemagogus spp.
Central and South America

Feeds on monkeys and other animals by day in forest canopy; occasional feeding on man at ground level, especially after trees are fallen. Flight limited.

Tree holes and other plant cavities in the forest

Mansonia titillans
North, Central and South America

Fierce biter of man and animals from dusk to dawn. Capable of long flights of several miles.

Ponds, lakes, impoundments with Pistia and other suitable plants, to which larvae and pupae can be attached by their air tubes

Psorophora confinnis
North, Central and South America

Fierce day and night-time biters of man and animals in vicinity of the breeding habitats. Observed flight: 8-13 km.

Temporary rain and flood pools

Ps. ferox
North, Central and South America

Fierce day and night-time biter in woods near breeding places. Observed flight: 2 km.

Temporary rain and flood pools

Sabettus chloropterus
Central and South America

A long-lived species with a preference for the forest canopy but also bites man at ground level.

Rot holes in trees

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D. Pest mosquitos

Tables 1.7 and 1.8 present the problem situations, species and distribution of some important pest mosquitos, their biting activity, breeding habitats and other biological characteristics.

Table 1.7. Important pest mosquitos

Problem situation	Species	Distribution	Biting activity		Breeding habitats*
			day	night	
(1) Dwellings	<u>Mansonia:</u>				
	<u>africana</u>	Ethiopian region	+	+	I.A.1
	<u>annulifera</u>	Oriental region	+	+	I.A.1
	<u>bonneae</u>	Malaysia, Philippines	+	+	I.A.1
	<u>dives</u>	Malaysia, India, Indonesia, Australia	+	+	I.A.1
	<u>indiana</u>	Malaysia, India, Indonesia	+	+	I.A.1
	<u>uniformis</u>	Oriental, Australian and Ethiopian regions	+		I.A.1
	<u>perturbans</u>	N. America	+	+	I.A.1
	<u>titillans</u>	N., C. and S. America	+	+	I.A.1
	<u>Aedes (F.) togoi</u>	Oriental region	+	+	I.A.7; IV.1,5
	<u>Ae. (S.) aegypti</u>	Tropics, subtropics	+		III.1,4,5,6,8
	<u>albopictus</u>	Oriental region, Australasia, Marianas, Hawaii	+		II.1,5,6,7; III.1,4,5,6,9
	<u>polynesiensis</u>	Polynesia	+		I.A.7,10; II.1,2,5,6,7 III.1,5,6
	<u>Armigeres</u>				
	<u>subalbatus</u>	Oriental region	+		I.A.5; III.2,3
	<u>Culex:</u>				
	<u>pipiens</u>	Holarctic region	+		I.A.2,5; III.1-8
	<u>pipiens fatigans</u>	Tropics, subtropics	+		I.A.2,5; II.6,7; III.1-8
	<u>annulirostris</u>	Australasia, Indonesia, Philippines	+	+	I.A.1,2,3 II.1,9
	<u>sitiens</u>	Oriental region, Australasia, Polynesia, E. Africa, Madagascar	+		I.A.7
	<u>vishnui</u>	Oriental region			I.A.1,3,7,8

* For an explanation of the symbols, please see page 259.

(2) Peridomestic; groves, etc.	<u>Mansonia uniformis</u>	Oriental, Australian and Ethiopian regions	+	+	I.A.1
	<u>Aedes (F.) kochi</u>	Australasia, Indonesia	+	+	II.2
	<u>Aedes (F.) poecilius</u>	Malaysia, Indonesia	+	+	II.2
	<u>Aedes (S.) albopictus</u>	Oriental region, Australasia, Marianas, Hawaii	+		II.1,5,6,7 III.1,4,5,6,9
	<u>pandani hebrideus</u>	Marianas New Hebrides, Solomon Islands, Santa Cruz, Torres, and Banks Islands	+		II.2 II.1,5,6,7 III.1,5,6,9
	<u>polynesiensis</u>	Polynesia	+		I.A.7,10; II.1,2,5,6,7 III.1,5,6
	<u>scutellaris</u>	Malaysia, Australasia, Indonesia, Philippines	+		II.1,5,6,7 III.1,5,6,9
	<u>simpsoni</u>	Ethiopian region	+		II.1,2
(3) Fields, pastures	<u>Culex (Culex) moucheti</u>	Ethiopian region	+	+	I.A.5
	<u>Psorophora confinnis</u>	N., C. and S. America	+	+	I.B.3
	<u>Aedes (O.) dorsalis</u>	Holarctic region	+		I.A.8,9 I.B.3
	<u>nigromaculipennis</u>	Western N. America	+		I.B.3
	<u>sollicitans</u>	N. America	+	+	I.A.8,9
	<u>Aedes (A.) vexans</u>	Holarctic and Oriental regions, Pacific Islands	+		I.B.3
	<u>Culex (Cx) annulirostris</u>	Australasia, Indonesia, Philippines	+		I.A.1,2,3
	<u>tritaeniorhynchus</u>	Oriental and Ethiopian regions, Middle East, Indonesia			III.1
	<u>baitaeniorhynchus</u>	Oriental and Ethiopian regions, Australasia	+		I.A.1,2,3,4,6 II.1

(4) Temperate zone woodlands	<u>Mansonia</u> <u>perturbans</u>	N. America, Europe	+	+	I.A.1
	<u>Psorophora</u> <u>cyanescens</u>	N. America	+	+	I.B.3
	<u>ferox</u>	N., C. and S. America	+	+	I.B.3
	<u>Aedes (C.):</u>				
	<u>canadensis</u>	N. America	+	+	I.B.3
	<u>cantans</u>	Europe, USSR, China	+		I.B.3
	<u>communis</u>	Holarctic region	+	+	I.B.2,3
	<u>rusticus</u>	Europe, N. Africa	+		I.B.3
	<u>sierrensis</u>	Western N. America	+		II.1
	<u>sticticus</u>	Holarctic region	+		I.B.3
	<u>triseriatus</u>	N. America	+		II.1
	<u>trivittatus</u>	N. America	+	+	I.B.3
(5) Tropical rain and swamp forests	<u>Mansonia:</u> <u>africana</u>	Ethiopian region	+	+	I.A.1
	<u>annulifera</u>	Oriental region, New Guinea	+	+	I.A.1
	<u>bonneae</u>	Malaysia, Indonesia, Philippines	+	+	I.A.1
	<u>dives</u>	Malaysia, Indonesia	+	+	I.A.1
	<u>fuscapennata</u>	Ethiopian region	+	+	I.A.1
	<u>titillans</u>	N., C. and S. America	+	+	I.A.1
	<u>Psorophora:</u>				
	<u>confinnis</u>	N., C. and S. America	+	+	I.B.3
	<u>ferox</u>	N., C. and S. America	+	+	I.B.3
	<u>Eretmapodites</u> <u>chrysogaster</u>	Ethiopian region	+		II.1,2,5,6,7 III.5
	<u>Aedes (O.):</u>				
	<u>scapularis</u>	C. and S. America	+	+	I.B.3
	<u>serratus</u>	C. and S. America	+	+	I.B.3
	<u>Ae. (A.) tarsalis</u>	Ethiopian region	+		I.B.3
	<u>Ae. (F.) leuco-</u> <u>celaenurus</u>	S. America	+		II.1
	<u>terrens</u> group	C. and S. America	+		II.1
	<u>Haemagogus:</u>				
	<u>chalcospilans</u>	C. and S. America	+		II.1,6
	<u>equinus</u>	C. and S. America	+		II.1,5
	<u>spiegazzinii</u>	S. America	+		II.1,5

(6) Coastal communities, recreational areas, etc.	<u>Aedes (O.): caspius</u>	Palaearctic region	+	+	I.A.8,9
	<u>detritus</u>	Palaearctic region	+	+	I.A.8,9
	<u>dorsalis</u>	Holarctic region	+	+	I.A.8,9
	<u>sollicitans</u>	N. America	+	+	I.A.8,9
	<u>taeniorhynchus</u>	N., C. and S. America	+	+	I.A.8,9
	<u>vigilax</u>	Australasia, Indonesia, Malaysia	+	+	I.A.8,10
	<u>Ae. (F.) togoi</u>	Coastal Siberia, East and South-East Asia	+	+	I.A.7; III.1,5
	<u>Culex (Cx) sitiens</u>	Coastal Oriental region, E. Africa, Madagascar, Northern Australia, S. and W. Pacific islands	+	+	I.A.8,9
(7) Meadows and woods of high mountains and Far North	<u>Aedes (O.) cataphylla</u>	Western N. America	+	+	I.B.2
		Europe	+	+	I.B.2
	<u>communis</u>	Palaearctic region	+	+	I.B.2
	<u>fitchii</u>	Northern N. America	+	+	I.B.2
	<u>hexodontus</u>	Northern N. America	+	+	I.B.2
	<u>implicatus</u>	Northern N. America	+	+	I.B.2
	<u>increpitus</u>	Western and Northern North America	+	+	I.B.2
	<u>pullatus</u>	Northern Holarctic region	+	+	I.B.2
	<u>punctor</u>	Northern Holarctic region	+	+	I.B.2
	<u>stimulans</u>	N. America	+	+	I.B.2
	<u>Ae. (A.) cinereus</u>	Northern Holarctic region	+	+	I.B.2
(8) Arctic tundra	<u>Aedes (O.) impiger</u>	Northern N. America	+		I.B.1
	<u>nigripes</u>	Arctic			

Notes on the larval breeding habitats of pest mosquitos
(Explanation of symbols used in Table 1.7.)

I. Groundwater

A. Permanent and semi-permanent quiet waters

1. Freshwater lakes, impoundments, ponds, borrow pits, swamps, sloughs, marshes, bogs, ditches, stream bed ponds and backwashes.
2. Small pools and puddles in ditches, drains and ground depressions caused by seepage, overflow, leaking water pipes, and rain in urban areas.
3. Ricefields.
4. Irrigated pastures.
5. Polluted sewage lagoons, settling ponds for industrial and agricultural wastes, sawmill log ponds, stagnant streams and canals, pit latrines.
6. Rock holes in freshwater stream beds.
7. Saltwater-filled rock holes along the sea coast.
8. Brackish and saltwater coastal marshes, lagoons, pools.
9. Inland saltwater pools.
10. Crab holes.

B. Temporary water

1. Snow- and ice-melt pools in the open arctic tundra.
2. Snow- and ice-melt pools in high mountains and the northern Palaearctic regions.
3. Temporary rain and flood pools, irrigated pastures, ricefields, marshes, etc. that are subject to alternate flooding and dewatering.

C. Margins of running streams and canals

II. Plant water-holding cavities

1. Tree holes.
2. Leaf axils of taro, banana, Pandanus, abaca, etc.
3. Epiphytic bromeliads.
4. Bamboo internodes.
5. Cut or split bamboo.
6. Coconut husks.
7. Fallen palm spathes and flower bracts.
8. Nipa palm base.

III. Man-made, artificial water containers

1. Water storage tanks, cisterns, barrels, watering troughs.
2. Sewer inlets and catch basins, cesspools.
3. Storm drains and street gutters.
4. Roof gutters.
5. Discarded tins, buckets, bottles.
6. Flower vases, pots.
7. Ornamental garden pools.
8. Cemetery urns.
9. Rainwater caught in canoes, etc.

Table 1.8. Distribution and biology of important pest mosquitos

Mansonia species

Distribution:	Cosmopolitan; temperate to tropical regions.																		
Adult habits:	Fierce biters in the vicinity of the breeding places, especially during the day or in the evening; some will bite also in houses during the night.																		
Breeding habitats:	Large permanent bodies of water — lakes, swamps, quiet rivers with abundant vegetation. Larvae and pupae are attached by breathing siphons to submerged vascular roots of aquatic plants, especially <u>Pistia stratiotes</u> .																		
Life cycle:	Eggs are deposited in rafts on the surface of the water, or are attached to the leaves of aquatic plants. Overwintering takes place in the larval stage.																		
Important species:	<table><tr><td><u>Ma. africana</u></td><td>- Ethiopian region.</td></tr><tr><td><u>Ma. annulifera</u></td><td>- Oriental region.</td></tr><tr><td><u>Ma. bonneae</u></td><td>- Malaysian region.</td></tr><tr><td><u>Ma. dives</u></td><td>- S.E. Asia, Australasia.</td></tr><tr><td><u>Ma. indiana</u></td><td>- S.E. Asia.</td></tr><tr><td><u>Ma. uniformis</u></td><td>- Ethiopian and Oriental regions, Australasia.</td></tr><tr><td><u>Ma. crassipes</u></td><td>- Oriental region, Australasia.</td></tr><tr><td><u>Ma. perturbans</u></td><td>- N. America.</td></tr><tr><td><u>Ma. titillans</u></td><td>- N., C. and S. America.</td></tr></table>	<u>Ma. africana</u>	- Ethiopian region.	<u>Ma. annulifera</u>	- Oriental region.	<u>Ma. bonneae</u>	- Malaysian region.	<u>Ma. dives</u>	- S.E. Asia, Australasia.	<u>Ma. indiana</u>	- S.E. Asia.	<u>Ma. uniformis</u>	- Ethiopian and Oriental regions, Australasia.	<u>Ma. crassipes</u>	- Oriental region, Australasia.	<u>Ma. perturbans</u>	- N. America.	<u>Ma. titillans</u>	- N., C. and S. America.
<u>Ma. africana</u>	- Ethiopian region.																		
<u>Ma. annulifera</u>	- Oriental region.																		
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<u>Ma. crassipes</u>	- Oriental region, Australasia.																		
<u>Ma. perturbans</u>	- N. America.																		
<u>Ma. titillans</u>	- N., C. and S. America.																		

Psorophora species

Distribution:	N., C. and S. America.
Adult habits:	Fierce biters, by day or night, in fields and woods in the vicinity of the breeding places.
Breeding habitats:	Temporary rain and flood pools; ditches and irrigated fields subject to intermittent flooding and dewatering.
Life cycle:	Eggs are deposited singly in the dry or moist soil of dewatered breeding places and are capable of resisting long periods of desiccation. Overwintering as in the egg stage.
Important species:	<u>Ps. ciliata</u> , <u>confinnis</u> , <u>cyanescens</u> , <u>ferox</u> .

Aedes, subgenus Ochlerotatus

Distribution: Cosmopolitan, but predominant in the Holarctic region.

Adult habits: These are the serious pest mosquitos of the arctic and subarctic regions, but also form an important component of the pest mosquitos in temperate and tropical regions. The females are fierce biters by day or night in the vicinity of the breeding places, but some species are capable of migrating for long distances and of creating a nuisance in communities far removed from the production sites.

Breeding habitats: Temporary rain or flood pools, lake margins, ponds, ditches, irrigated fields, bogs, swamps, and marshes subject to intermittent flooding and dewatering.

Life cycle: Eggs are deposited singly on the soil of the dewatered habitat. Those of some species are capable of surviving desiccation for as long as 4 years. Overwintering takes place in the egg stage. In northern regions there is one generation per year; further south there may be two or more.

Important species:

<u>Ae. canadensis</u>	- Nearctic region; freshwater pools.
<u>Ae. caspius</u>	- Palaearctic region; freshwater pools; coastal marshes.
<u>Ae. communis</u>	- Holarctic region; early spring freshwater pools, including snow pools.
<u>Ae. detritus</u>	- Palaearctic region; coastal saltwater marshes and inland saltwater pools.
<u>Ae. dorsalis</u>	- Holarctic region; fresh and brackish water, snow, rain, and flood pools.
<u>Ae. excrucians</u>	- Holarctic region; freshwater pools.
<u>Ae. nigripes</u>	- Arctic regions of N. America, Europe, Asia; snow and ice pools.
<u>Ae. nigromaculatus</u>	- Nearctic region; rain pools, irrigated fields, ditches.
<u>Ae. punctator</u>	- Northern Holarctic region; snow and ice pools, bogs.
<u>Ae. scapularis</u>	- Southern N. America, C. and S. America; rain and flood pools.
<u>Ae. serratus</u>	- C. and S. America; rain and flood pools.
<u>Ae. sollicitans</u>	- USA; east coast salt marshes, inland salt pools.
<u>Ae. sticticus</u>	- N. Holarctic region; rain and flood pools.
<u>Ae. stimulans</u>	- Nearctic region; snow, rain and flood pools.
<u>Ae. taeniorhynchus</u>	- Atlantic coast from New England to Brazil; Pacific coast from California to Peru; inland salt pool areas, salt marshes and saltwater pools.
<u>Ae. trivittatus</u>	- N. America; rain and flood pools.
<u>Ae. vigilax</u>	- Malaysia and Australasia; brackish water swamps and marshes, freshwater ground and rock pools.

Aedes, subgenus Finlaya

Distribution:	Cosmopolitan, especially in tropics and subtropics.										
Adult habits:	Adults are encountered primarily in woods, forests, and plantations where they attack by day or night, indoors as well as outdoors.										
Breeding habitats:	Leaf axils of taro, banana, abaca, <u>Pandanus</u> , etc.; tree holes, rock holes, artificial containers.										
Life cycle:	Eggs are deposited singly above the water line, and may survive long periods of desiccation. In most northern regions there are several generations per year; here winter is passed in the egg stage. Breeding is continuous in the tropics or subtropics, depending upon the availability of water.										
Important species:	<table><tr><td><u>Ae. kochi</u></td><td>- Australian region.</td></tr><tr><td><u>Ae. poecilius</u></td><td>- S.E. Asian and Australian regions.</td></tr><tr><td><u>Ae. togoi</u></td><td>- Oriental region.</td></tr><tr><td><u>Ae. triseriatus</u></td><td>- N. America.</td></tr><tr><td><u>Ae. fijiensis</u></td><td>- Fiji.</td></tr></table>	<u>Ae. kochi</u>	- Australian region.	<u>Ae. poecilius</u>	- S.E. Asian and Australian regions.	<u>Ae. togoi</u>	- Oriental region.	<u>Ae. triseriatus</u>	- N. America.	<u>Ae. fijiensis</u>	- Fiji.
<u>Ae. kochi</u>	- Australian region.										
<u>Ae. poecilius</u>	- S.E. Asian and Australian regions.										
<u>Ae. togoi</u>	- Oriental region.										
<u>Ae. triseriatus</u>	- N. America.										
<u>Ae. fijiensis</u>	- Fiji.										

Aedes, subgenus Stegomyia

Distribution:	Asian and Ethiopian regions. One species, <u>aegypti</u> , has achieved a tropicopolitan distribution.												
Adult habits:	Adults rest in the shelter of vegetation in the vicinity of the breeding habitats, and bite primarily by day when their haunts are invaded. Some species are encountered only in their sylvan environment; others are peridomestic and bite indoors as well as outdoors. One species, <u>aegypti</u> , comprises both outdoor and domestic populations.												
Breeding habitats:	Plant cavities, including leaf axils of taro, banana, and <u>Pandanus</u> ; palm spathes, bamboo stumps, coconut husks, tree holes, and artificial containers including tins, jars, barrels, tanks and vases.												
Life cycle:	Eggs are deposited singly above the water line in the appropriate container. Here they may survive desiccation for long periods of time; dry season survival takes place in the egg stage. Breeding is continuous depending on the availability of water.												
Important species:	<table><tr><td><u>Ae. aegypti</u></td><td>- Tropics, subtropics.</td></tr><tr><td><u>Ae. albopictus</u></td><td>- Oriental and Australian regions, Djibouti and Madagascar.</td></tr><tr><td><u>Ae. guamensis</u></td><td>- Marianas.</td></tr><tr><td><u>Ae. polynesiensis</u></td><td>- Polynesia.</td></tr><tr><td><u>Ae. scutellaris</u></td><td>- Indonesia, Melanesia, Philippines, Palau, and Caroline Islands.</td></tr><tr><td><u>Ae. simpsoni</u></td><td>- Ethiopian region.</td></tr></table>	<u>Ae. aegypti</u>	- Tropics, subtropics.	<u>Ae. albopictus</u>	- Oriental and Australian regions, Djibouti and Madagascar.	<u>Ae. guamensis</u>	- Marianas.	<u>Ae. polynesiensis</u>	- Polynesia.	<u>Ae. scutellaris</u>	- Indonesia, Melanesia, Philippines, Palau, and Caroline Islands.	<u>Ae. simpsoni</u>	- Ethiopian region.
<u>Ae. aegypti</u>	- Tropics, subtropics.												
<u>Ae. albopictus</u>	- Oriental and Australian regions, Djibouti and Madagascar.												
<u>Ae. guamensis</u>	- Marianas.												
<u>Ae. polynesiensis</u>	- Polynesia.												
<u>Ae. scutellaris</u>	- Indonesia, Melanesia, Philippines, Palau, and Caroline Islands.												
<u>Ae. simpsoni</u>	- Ethiopian region.												

Aedes, subgenus Aedimorphus

Ae. vexans - Holarctic and Oriental regions, Pacific islands. Adults bite by day or night in the vicinity of the breeding place. Breeding habitats are rain and flood pools; winter is passed in the egg stage; one to several broods per year depending on the latitude.

Haemagogus species

Distribution: Neotropical region.

Adult habits: These are forest-inhabiting mosquitos. Adults will attack at ground level when their haunts are invaded, but are most abundant in the forest canopy.

Breeding habitats: Plant cavities, including tree holes and bamboo stumps.

Life cycle: Continuous breeding depending on the availability of water. Dry season survival takes place in the egg stage, which can survive desiccation.

Important species: H. spegazzinii - S. America
H. sp. falco - C. and S. America.

Culex species

Distribution: Cosmopolitan.

Adult habits: Annoying species such as Cx pipiens and Cx quinquefasciatus are strongly domestic, and enter houses to feed on the inhabitants by night. Feeding may also take place out of doors during the evening or night. Endophilic populations rest in houses, especially dark corners of bedrooms, or in nearby shelters such as sheds, bridge abutments, culverts, etc. Exophilic species attack during the evening or at night in the vicinity of their breeding habitats.

Breeding habitats: Groundwater, including lake margins, impoundments, slow streams; ditches, pools and irrigated fields; domestic species are also found in artificial containers such as barrels, tanks, tins, and vases.

Life cycle: Eggs are laid in rafts on the surface of the water. They do not withstand desiccation and hatch within about 2 days. There are several generations during the summer in temperate regions; in the autumn the fertilized females accumulate carbohydrate reserves and hibernate in a suitable shelter. In the tropics, breeding is continuous.

Culex species (cont.)

Important species:

<u>Cx annulirostris</u>	- Australian region, Indonesia, Philippines.
<u>Cx mouchetti</u>	- Ethiopian region.
<u>Cx pipiens</u>	- Worldwide in temperate regions.
<u>Cx quinquefasciatus</u>	- Worldwide in tropics and subtropics.
<u>(fatigans)</u>	- Oriental and Ethiopian regions,
<u>Cx sitiens</u>	Australasia.
<u>Cx tritaeniorhynchus</u>	- Oriental region, Africa, Middle-East
<u>Cx univittatus</u>	- Ethiopian, Indian, and Mediterranean regions.

Annex 2

LIST OF ENVIRONMENTAL MANAGEMENT MEASURES WHICH HAVE PROVED TO BE USEFUL
IN THE PREVENTION AND CONTROL OF MALARIA AND SCHISTOSOMIASIS

The following environmental management measures have been applied for the prevention and control of malaria and schistosomiasis. They serve to create conditions unfavourable to the breeding and propagation of vectors and intermediate hosts, to reduce opportunities for man/mosquito contact or man/cercaria-infested water contact, and to assist in the application of insecticides and molluscicides. Although specifically addressed to water resources development projects, the measures are equally applicable to other situations.

The letters (M) or (S) indicate that the measure is particularly applicable to malaria or schistosomiasis control respectively. No indication is given where the measure is equally applicable to the control of both diseases.

During the design and construction phases

A. In reservoirs and surrounding areas

1. Removal of all trees, bushes and other plants that would emerge at maximum drawdown water level of the reservoir.
2. Selective clearing of vegetation in the zone of water level fluctuation about 8 m beyond the normal full reservoir contour at heads of bights for stranding of drifts (see subchapter IIIA), and much further on open shorelines.
3. Straightening of margins through cutting, deepening and filling of the reservoir edge.
4. Construction of dikes and levees to separate shallow bays from the reservoir and dewatering of the low areas behind the dikes by the operation of gates, so that the water flows by gravity when the reservoir is at low level or by pumping. Dewatering of runoff from drainage areas behind the dikes.
5. Removal of earth from higher areas that would protrude as small islands at maximum drawdown water level of the reservoir.
6. Filling of natural or man-made depressions in the vicinity of the reservoir, or draining of these depressions by ditches leading to the reservoir.
7. Provision in the dam design for the periodic fluctuation of water level. Large size crest gates (Tainter gates).
8. Paving or lining of spillways and diversion channels where they are exposed to wave action and erosion.
9. Use of waterproof membranes of clayey or plastic material at the base and surroundings of the dam to reduce water seepage, and provision of drainage for possible seepage water.
10. Building of boat operating bases, either by the construction of jetties or by the digging of small channels for the docking of boats. Ramps for launching of boats.

11. Provision of paths and other means of access to the reservoir edge for vegetation clearance and pesticide application.
- (S)12. Extension into the reservoir of the drawout structure or outlet conduit so that water is not taken from the edge.
- (S)13. Screening of intakes to prevent the passage of snails.
- (S)14. Locating intakes of large lakes and reservoirs below the euphotic zone. Below this zone, where sunshine does not penetrate, there should be no snails.
- (S)15. Fencing of the reservoir in the vicinity of villages to discourage people from using the reservoir.

B. In irrigation systems

1. Design of main canals, laterals and sublaterals to follow straight lines with the minimum number of bends; any necessary bends should be of ample curvature.
2. Design of canal gradients and cross-sections to ensure water velocities that prevent both silting and scouring.
3. Design of canal grids without interconnexions so that water enters at the head (or upper) end and flows in one direction only.
4. Provision of a gate, siphon or other water control device at the tail (or lower) end of canals so that they can be flushed and emptied to the nearest drain when necessary.
5. Provision of an effective drainage system to collect and dispose of surface and ground surplus water.
6. Elimination of disused canals and drains, and of natural streams intercepted by the new system.
7. Filling or draining of borrow pits along canals and roads. Land levelling.
8. Paving or lining of canals as extensively as possible; this is an irrigation improvement as well as an effective health protection measure.
9. Consideration in the design to using covered conduits or pipes for water distribution to cultivated plots and for surplus water drainage.
10. Provision of a sufficient number of bridges across canals so that the villages are not isolated from the main roads; this will also help the maintenance work and the application of insecticides and molluscicides.
11. Protection of the canal section at the entrance and exit of culverts, drops, chutes, control structures, etc. against scouring that may form depressions.
12. Designation of "dry belting" areas around villages, and land occupancy and restriction measures.

C. In communities

1. Selection of sites for villages on high ground with a slight and uniform slope, with sandy top soil that allows water infiltration; filling of any ground depressions.
2. Location of villages away from the edge of the reservoir or the banks of rivers and canals. A distance of 1.5-2 km has proved to be adequate in reducing the incidence of malaria; this same distance will discourage people from contact with schistosome-infected water.
3. Location of animal sheds and stables with a view to encouraging zooprophylaxis.

(S)4. Provision of a safe water supply in every settlement; the type of supply in accordance with local conditions and importance of the community.

(S)5. Provision of public facilities for laundry, bathing and recreation of suitable capacity. If needed, provision of cattle troughs.

(S)6. Provision of excreta disposal installations suitable to soil conditions and of a type in keeping with the importance of the community.

7. Provision of open or closed conduits for the rapid collection, transport and disposal of rainwater in accordance with the climate of the locality.

(M)8. Mosquito proofing of houses and selection of appropriate housing designs that are unfavourable to mosquitos.

During the maintenance and operation phases

A. In reservoirs and surrounding areas

1. Clearing of submerged, emerging and floating vegetation to keep a bare zone of water level fluctuation and a clean shoreline.
2. Dredging of the reservoir margin to deepen it and produce steeper slopes.
3. Repair of dikes and levees to keep them in proper condition.
4. Filling or draining of natural and man-made ground depressions of recent formation or those that were unnoticed at the time of construction.
5. Straightening of courses and rectification of gradients of natural streams conveying water from the catchment area to the reservoir.
6. Provision of proper management for the punctual operation of water level fluctuation.
7. Repair of spillways, diversion channels and other structures scoured by water, and paving of the damaged sections.
8. Repair of drains that collect and convey the seepage water coming from the dam or other structures.

- (S) 9. Repair of grids and screens at the intake structures or suction pipes.
- (S) 10. Fencing of the reservoir may be advisable when the communities have been provided with a proper water supply.
- 11. Repair of roads and paths of access to the reservoir edge.

B. In irrigation systems

- 1. Dredging of canals and drains to bring them back to their original dimensions and correct gradients, reshaping of cross-sections, and filling of bed depressions that may retain water when empty.
- 2. Frequent clearing of vegetation to ensure that the canals and drains are free from aquatic plants, weeds, etc.
- 3. Avoidance of the use of canals for night storage.
- 4. Repair of control structures and gates to ensure their proper functioning.
- 5. Repair of culverts, siphons and bridges, and filling of bed depressions formed by scouring at their entrances and exits.
- 6. Effective control of water quantity at the intake of the irrigation reservoir and at the gates to prevent over-irrigation.
- 7. Levelling and grading of cultivated land, particularly where it is exposed to flooding, or provision of drainage when levelling and grading is too extensive.
- 8. Gradual lining of canals, starting in the sections most exposed to scouring and those where seepage losses are greatest.
- 9. Gradual transformation of open channels to covered conduits and pipes, starting in the sublaterals and feeding canals. Promotion of subsurface drainage.
- 10. Gradual improvement of irrigation practices and methods (intermittent irrigation, localized sprinkler irrigation, etc.); gradual improvement in agricultural practices.
- (M) 11. Restriction of land use to daytime work in order to reduce the opportunities for mosquito biting.
- 12. Periodic flushing of canals and drains.

C. In communities

- (S) 1. Maintenance, extension and improvement of water supply installations in accordance with the development of the community and the amelioration of living conditions.
- (S) 2. Improvement and transformation of waste disposal installations in accordance with the development of the community and amelioration of living conditions.
- 3. Maintenance, extension and improvement of the rainwater collection and disposal systems.
- (M) 4. Introduction of a public service for the collection of household and other wastes.
- (M) 5. Mosquito proofing of houses, and promotion of individual protection.

Annex 3

MATRIX FOR THE STUDY AND ANALYSIS OF THE ENVIRONMENTAL IMPACT OF A RESERVOIR
IN A WATER RESOURCES DEVELOPMENT PROJECT

The matrix presented below is composed of two lists. One is of the actions (works and operations) of the proposed project that may have an impact on the environment; these form the headings of the vertical columns. The other list is of the environmental factors which together make up the existing ecological system of the area; each of these follows a horizontal column. A mark on one of the blocks or squares formed by the intersecting columns and lines indicates a relation between the corresponding action (head of the vertical column) and environmental factor (on the left).

The matrix can be used for two purposes. First, as a checklist or reminder of the full range of actions and impacts that should be taken into account in the planning and programming of the main studies for the analysis of the ecological impact. A mark on each relevant block of the matrix will indicate that a particular proposed action is expected to produce an effect on a particular factor of the existing environment. A plus (+) or minus (-) sign on the block could indicate that a beneficial or detrimental effect (respectively) is foreseen. The original matrix, used as a checklist to cover all possible subjects requiring study, may have to be adjusted, shortened or extended, to conform with the findings of these studies, so that the second matrix used for the evaluation of the impact is closer to reality.

The second use of the matrix is to present summarily the results obtained from these studies, using a conventional scale of values to indicate the relative intensity and extent of the expected effect. In practice, a scale of values ranging from 1 (for the lowest influence) to 10 (for the highest) has proved to be adequate; a (+) or (-) sign added to the number will show whether the influence will be beneficial or detrimental. Only through experience will an evaluator acquire the skill to judge accurately and impartially the relative influence of each effect that may intervene in the assessment of the total impact.

In each relevant block of the matrix there should be two numbers separated by a diagonal line; one will represent the magnitude or intensity, the other will represent the importance or extent of the effect.

The matrix covers most of the main actions involved and environmental factors affected. It is by no means complete and should not be taken as a model but as a guide. Each situation requires the preparation of its own particular matrix.

Other applications of the matrix

(a) The matrix can be used for the determination of the overall ecological impact of the vector control measures of an antimalaria programme. For this the matrix should have a column for each proposed control measure — for instance, larviciding, residual spraying, vegetation clearance in the reservoir, drainage of the surrounding area, and desilting and weed control in canals. Each action is analysed to assess the ecological effect it may produce on all the environmental elements listed on the left, and the results are recorded in the corresponding intersection boxes.

(b) Likewise, for the determination of the impact on malaria transmission that may result from a water resources development project, the matrix should have a vertical column for each of the proposed actions of the project that may have an effect on mosquito populations and densities and on man/vector contact. Each action is analysed to assess the effect it may produce on malaria transmission by influencing any of the relevant environmental factors; each of the latter should have a horizontal space in the matrix.

In the application of (a) above, the matrix will give a picture of the magnitude and importance of the ecological impact, whether beneficial or detrimental, that may be expected from the antimalaria programme. In the application of (b), the matrix will show the impact on malaria transmission, whether beneficial or detrimental, that may result from a water resources development project.

MATRIX FOR THE STUDY AND ANALYSIS OF THE ENVIRONMENTAL IMPACT OF A RESERVOIR
IN A WATER RESOURCES DEVELOPMENT PROJECT

Proposed actions that may cause environmental impact

PHYSICAL AND CHEMICAL CHARACTERISTICS				Construction activities for land transformation	Water and land regime alteration	Operational activities	Human communities
PROCESSES	AIR	WATER	EARTH				
Land formation				Dam and impoundment			
Soil constitution				Offshore structures			
Mineral resources				Dredging and straightening			
Construction materials				Diking and dewatering			
Surface				Draining and filling			
Underground				Vegetation clearance			
Recharge				Blasting and drilling			
Quality				Noise and vibration			
Climate				Water hydrology			
Dust, smoke				Stream flow and control			
Quality				Erosion control			
Floods				Drainage			
Erosion				Ground cover			
Silting				Vegetation cover			
Landslides				Energy generation			
Earthquakes				Food production			
				Cattle grazing			
				Recreation amenities			
				Navigation			
				Weed control			
				Insect control			
				Workers' camps			
				Scattered houses			
				Villages and towns			
				Roads and paths			

ECOLOGICAL RELATIONSHIPS	CULTURAL FACTORS				
	MAN-MADE WORKS	HUMAN STATUS	AESTHETICS AND INTEREST	RECREATION	LAND & WATER USE
BIOLOGICAL CONDITIONS	FLORA	Crops Trees and shrubs Grass and weeds Aquatic plants Endangered species			
	FAUNA	Insects Fish Birds Land animals Endangered species			
	Agriculture Forestry Grazing Fishing Hunting Human settlements				
	Boating and swimming Camping and hiking Resorts				
	Wilderness Open space Parks and reserves Monuments Historical sites				
	Cultural patterns Population density Employment Health and safety				
	Industries Structures Transport networks Utilities networks Waste disposal				
	Food chains Water degradation Brush encroachment Eutrophication Disease vectors Others				

Annex 4

CHECKLIST OF MAJOR STEPS FOR THE PREVENTION AND CONTROL OF VECTOR-BORNE DISEASES
AT EACH PHASE OF WATER RESOURCES DEVELOPMENT PROJECTS

PLANNING PHASE

(1) Review of existing information on health and related subjects

- (a) Epidemiology: morbidity and mortality rates, geographic distribution, vector ecology.
- (b) Health and medical services: facilities, staff, special projects and programmes, degree of development, capacity and coverage.
- (c) Human population and characteristics: agricultural, migrant, nomadic (and other) population growth, importance of migratory movement, displacement within the project area.
- (d) Cattle: number and economic importance, cattle diseases.
- (e) Community and housing patterns: location, design, construction materials.
- (f) Water supply, excreta and waste disposal facilities.
- (g) Climatic patterns: temperature, rainfall, humidity, wind, etc.
- (h) Water: surface water and groundwater, quality, pollution, abundance and seasonal variation, floods and droughts, seasonal variation in temperature.
- (i) Soil: physical and chemical characteristics, including permeability, stability, salt content, etc.
- (j) Natural and cultivated aquatic and land vegetation, domestic and wild animals.
- (k) Economy: national and local, sources and levels of income.
- (l) Topographic maps: contour lines, roads, villages, etc. of the region and the watershed, design plans of proposed project, etc.

(2) Surveys: To check information or fill in gaps; collection and assessment of basic data by specialists

- (a) Detailed epidemiology of major existing diseases and biology and ecology of principal vectors.
- (b) Health and medical services, disease and vector control programmes and activities, evaluation of effectiveness and resources.
- (c) Human and cattle movements: migratory currents, their origin and paths.
- (d) Sanitation: sources of water supply (in use and potential), investigation of groundwater sources, active and potential sources and ways of pollution, practices with water contact, excreta disposal, cattle watering and manure disposal.
- (e) Existing and proposed agricultural crops and practices: irrigation methods, suitable crops, rotation in cultures and irrigation, use of pesticides and fertilizers, their kind and amount.
- (f) Local economy: at present, and prospects of future development.
- (g) Sociocultural patterns: present level, and possible disturbance as a result of the project.
- (h) Engineering and operational reconnaissance and mapping for ecological, hydrological and geological (or soil) studies.
- (i) Contact with agencies operating in the project area, type of their activities, and possibility for assistance and coordination.

(3) Decision-making for the prevention and control of diseases

- (a) Review of project proposals and preliminary designs and options.
- (b) Identification of existing health problems.
- (c) Prediction of possible future problems and of their health effects.
- (d) Determination of the importance and extent of actual and potential health problems to establish an order of priorities in prevention and control operations.
- (e) Feasibility studies of control measures, including cost/effectiveness and cost/benefit analysis.
- (f) Selection of village sites and types of water supply and excreta disposal installations.
- (g) Selection of methods of vector and disease control and estimates of manpower and organizational requirements.
- (h) Organization of field trials and pilot projects.
- (i) Settlement of displaced and immigrant populations and estimates for the provision of water supply, sanitation and other health facilities.

DESIGN PHASE

- (1) Establishment of design criteria to minimize health hazards and to achieve the objectives of the health programme.
- (2) Evaluation of preliminary project designs and alternatives.
- (3) Establishment of proposed practices of water system management and their effects on vector habitats.
- (4) Preliminary design and options for canal lining, overpasses, and other health protection structures.
- (5) Final detailed design of works in the reservoir:
 - (a) Shoreline modification and improvement.
 - (b) Clearance and disposal of trees and brush, man-made structures and fences.
 - (c) Relocation of roads, villages, cemeteries, shrines, etc.
 - (d) Discharge structures sized for water level management and downstream flushing.
- (6) Final detailed design of works in irrigation schemes:
 - (a) Equalizing reservoirs and night storage ponds, when necessary.
 - (b) Canals and drains.
 - (c) Regulating structures, gates, sluices, etc. and distributing chambers.
 - (d) On-farm water use.
 - (e) Groundwater use and control.
 - (f) Potential for incorporating domestic water supply.
- (7) Final detailed design of measures and works in communities:
 - (a) Selection of sites (distant from water) for new communities.
 - (b) Provision of safe, adequate and convenient water supply and sewage disposal systems.
 - (c) Recreation, safe ponds as alternative to infected water contact, sports grounds, etc.
 - (d) Other protective measures, such as house screening, surface water drainage, general sanitation, public laundry installation, etc.
- (8) Provisions for maintenance activities and their financing.

- (9) Environmental management:
 - (a) Regulating structures for measurement and control of water discharge and velocity.
 - (b) Gates required for rapid drying and flushing of irrigation subsystems.
 - (c) Adjustment of water salinity in coastal breeding sites through the installation and operation of gates.
 - (d) Water level management in small reservoirs by means of automatic siphon spillways.
 - (e) Safe crossings and bridges over canals and drains.
 - (f) Lining of canals and drains, closed or subsurface conduits.
- (10) Improvement and simplification of chemical and biological control:
 - (a) Design dispensers for chemical application attached to or incorporated in regulating structures; metal rakes and screens against snails.
 - (b) Provide access roads and paths for surveillance and spraying, clear water lanes and landings for boats.
- (11) Public health education and development of community participation.
- (12) Health facilities — dispensaries and hospitals.

CONSTRUCTION PHASE

- (1) Health protection of the construction labour force.
- (2) Special facilities for disease control and treatment at the construction site.
- (3) Adequate housing and sanitary facilities for construction workers and their families.
- (4) Surveillance of infections in imported manpower and the local population.
- (5) Monitoring, vaccination and treatment of the local population, and elimination and control of endemic diseases, especially those with potential for intensification as a result of the project operation.
- (6) Environmental protection, erosion, spillage, air and water pollution, disposal of wastes, aesthetic alterations, etc.
- (7) Inspection to ensure that construction is carried out according to the health designs.
- (8) Public health education and development of community participation.

OPERATION PHASE

- (1) Allocation of funds, assignment of staff and implementation of disease control programmes.
- (2) Surveillance, screening and treatment of infected persons.
- (3) Establishment of rule curves and schedules for the control of mosquitos, snails, flies, weeds, etc.
- (4) Establishment of water level management practice and schedules.
- (5) Maintenance and modernization of structures and other works.

- (6) Application of chemical and biological methods for vector and weed control.
- (7) Drainage of all water collections around the reservoir.
- (8) Prevention and correction of excessive seepage.
- (9) On-farm water management.
- (10) Operation, maintenance, improvement and development of water supply and sewage disposal systems, general sanitation.
- (11) Public health education and development of community participation.
- (12) Evaluation of vector and disease pattern changes, efficacy of control programmes, study and implementation of amendments or alterations to improve results.
- (13) Preparation of periodic and special reports for information.

Annex 5

EQUIPMENT FOR ENVIRONMENTAL MANAGEMENT

1. Plough ditchers

Plough and blade ditchers are common. They have no moving parts, are comparatively cheap, and are available in sizes suitable for pulling by all sizes of tractors.

The ordinary single-furrow mouldboard plough can be used to cut a roughly rectangular-shaped ditch of dimensions limited by the plough components. The soil turned out from the furrow is deposited on one or both sides depending on the design (Figs. 1 and 2). Coulters may be either of the knife or rolling-disk type. Knives are generally preferred on stony soil as they allow a more even working depth to be maintained. Special ploughshares to cut a U-shaped furrow bottom are sometimes fitted and are favoured when cutting surface drains in grass land.

2. Furrow-type ditchers

The true "furrowing" plough, as developed in Europe, is particularly suitable for work under very wet conditions. It has two mouldboards so arranged that half of the soil is turned to the left and half to the right side of the ditch that is cut. To push the soil further away from the ditch wall, wings can be fitted to the rear of each mouldboard (Fig. 3). On the larger model drawn by heavy tractors, the mouldboard can be extended into shaped pieces which form the excavated soil into the required bank contour. On the larger ploughs, a third centrally mounted coulter is sometimes fitted ahead of the shear to cut the furrow slash longitudinally before the soil is lifted up and turned by the mouldboards.

In operation with both the single and double mouldboards for ditching ploughs, the tractor is driven along the line of the ditch. The working depth is controlled by altering the pitch of the body and raising or lowering the plough beam in relation to the supporting wheels or skid. On the larger tractor-drawn models, depth is controlled hydraulically or by cable and winch.

This type of ditcher is used for cutting surface drains in soft soils and for the preliminary drainage of very wet land before reclamation. Where the land is very soft and both ditchers and tractors may become bogged down, especially wide wheels or tracks can be fitted to the ditcher.

3. The V-drag ditcher

A very simple implement, the V-drag ditcher (Fig. 4), not to be confused with the American V-blade ditcher, can be constructed by any rural carpenter and smith. It is an inexpensive and effective implement for both the construction and the maintenance of small ditches.

Both single and double mouldboard ditching ploughs can be used for cleaning and restoring the profile of the ditches they have cut, providing the tractors can straddle the ditch or the ploughs can be sufficiently offset.

4. The V-blade ditcher

The double-blade or American V-type ditcher consists basically of two blades attached to each other to form a "V" (Fig. 5). The lower edge of each blade is sharp, and this enables the ditcher both to cut and to finish the ditch wall. The spoil moves upwards along the blade and is deposited at both sides of the ditch. Depth is controlled by adjusting the drawbar to restrict the downward movement of the beam, and the angle of penetration can also be altered. Both deep and shallow work can be done. There are models for all sizes of tractors and they can be trailed or mounted on the hydraulic three-point hitch. Blade ditchers, while particularly efficient and fast working in hard dry soils, are generally much less suitable than the mouldboard type on wet soils which do not scour well.

5. Excavators (backhoes)

Small hydraulically operated machines can be used as mobile excavators. Fitted with suitable buckets they can both cut and clean irrigation and drainage ditches. A number of manufacturers are now making hydraulically operated ditch-cutting and cleaning equipment for use with standard agricultural tractors (Fig. 6). The main advantages offered by farm-tractor-mounted excavators are:

- (a) They are very mobile and can be moved from one worksite to another without special transport.
- (b) Hydraulic control gives very accurate placing of the bucket, and one-man operation can be accurate and efficient.
- (c) The tractors can be quickly converted back to their normal form and used for farm work.
- (d) Buckets of various sizes and shapes allow the machines to be used for a wide variety of both agricultural and civil engineering work; this makes them especially attractive to a contractor.

The majority of these machines are mounted at the rear of the tractor and the buckets are arranged so that the digging tine or cutting edge is pulled toward the key post to which the boom and digging arms are fastened. Reach and working depth depend largely on the length of the boom and digger arms. On larger machines, the digging depth can be up to 5.2-6.0 m and the reach can be from 3.6-4.3 m. With all types of bucket ditchers or backhoes, the output falls when liquid or semiliquid spoil has to be dealt with. The best performance with these types is obtained in fairly dry materials.

The small ditchers, designed for use with standard agricultural tractors, can be operated from the hydraulic systems on the tractors. In most cases, small tractor-mounted ditchers are of small capacity. Larger models are permanently mounted; they are used in civil engineering work as well as for digging open drains.

6. Dragline

A dragline is much used in civil engineering work. It is usually self-propelled and mounted on tracks. Its power varies from 30 to 120 hp and digging rates vary from about 20 to 100 m³/h. In recent years, draglines have been increasingly used by irrigation and drainage authorities for cutting and cleaning large open ditches.

Straight drag and back-acting excavators (draglines), when used for cutting, are driven along the line of the ditch. As the bucket is virtually free-swinging from the cables, it is seldom possible for it to finish the wall and banks to exact specifications. The walls very

often need to be trimmed by hand or by another machine such as a grader or a gradall. Despite this seeming disadvantage, an experienced operator can do surprisingly accurate work with a dragline, and he can considerably reduce the amount of labour required for finishing. Cable-operated or dragline excavators are suitable for cleaning ditches only under special conditions, when the ditch is narrow enough to be straddled by the excavator and when both banks are unobstructed and able to bear the weight of the machine. A ditch to be excavated or cleaned with a dragline (Fig. 7) should have the proper cross-section or width for the bucket to be pulled across with the same action as a scoop ditcher or front-end bucket loader.

When used for cleaning wet ditches, the output of a dragline is greatly reduced and, while larger buckets with drain holes may give better results, it is always better to drain the ditch before cleaning. Secondary irrigation ditches are fairly easily drained, but those which constantly carry water may have to be temporarily dammed and the water pumped out before dragline cleaning starts.

7. Trenchers for laying plastic drain tubing

Plastic tube drain installation may be done by several types of trenching machines, but the two most commonly employed by contractors are the bucket-wheel type (Fig. 8) and the trenchless or plough type. The bucket-wheel type of trencher has a large wheel mounted on a frame at the rear of the machine. The wheel can be moved up and down by power to keep the machine on grade. Attached to the wheel are excavating buckets. Immediately behind the bucket-wheel is a cutting shoe and a shield to keep the loose earth from falling into the trench. The cutting shoe shapes the bottom of the trench for the drain. The shield is long enough to allow the drain tubing to be placed in a clean trench within the shield. The excavating buckets carry the excavated material upward and place it on a conveyor which deposits it on the ground at one side of the trench.

Different sizes of bucket-wheel-type trenchers are available for various depths and widths of the required excavation. They may be mounted on wheels or on semicrawler or full-crawler frames. Buckets may be changed to fit the type of soil in which the excavation is to be made.

8. Trucks

Trucks are commonly used in irrigation projects because they can haul earth materials at high speeds over distances as long as required. Trucks are available in small to large sizes. The truck shown in Fig. 9 has a capacity of approximately 30 m^3 . It is capable of operating off the highway and of hauling earth from any excavation site to any fill site. The truck body is heavy and can carry large rock as well as earth materials.

9. Rotary ditchers

The ditcher is equipped with a box of the same shape as the ditch. The box keeps the ditcher on course and makes for true cutting. The cutting blades are mounted on a wheel on one or both sides of the box; they cut the laterals of the ditch as the wheel rotates. The soil is pulverized on the ditch sides 6-15 m away from the edge. The ditcher is towed by a tractor and is free to move up or down.

Several types are available. One make can be used with tractors from 35 to 100 hp for the single-wheel type and from 90 to 140 hp for the double-wheel type. These can dig ditches 0.7-1.9 m wide with 0.24-0.30 m base and 0.40-1.25 m depth. They weigh from 320 to 1130 kg. The equipment is rather inexpensive (US\$ 700-3000 at 1980 prices) and the most expensive one costs less than a field vehicle (see Fig. 10).

Many other types of construction equipment are manufactured for several purposes; however, the types described above are the general types used on most earth construction projects. In Table IIIH-1 (see subchapter IIIH), the equipment is divided into small, medium and heavy types with descriptions of the use of the different machines.

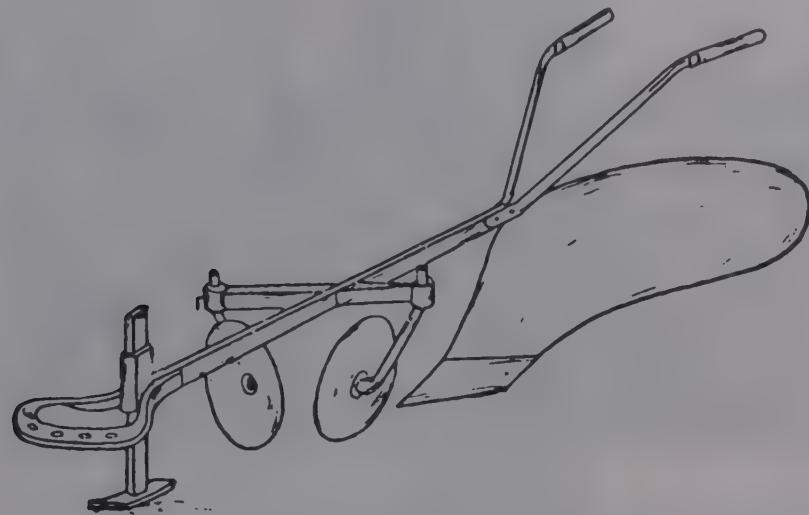


Fig. 1. Mouldboard plough fitted with two coulters for cutting small ditches.

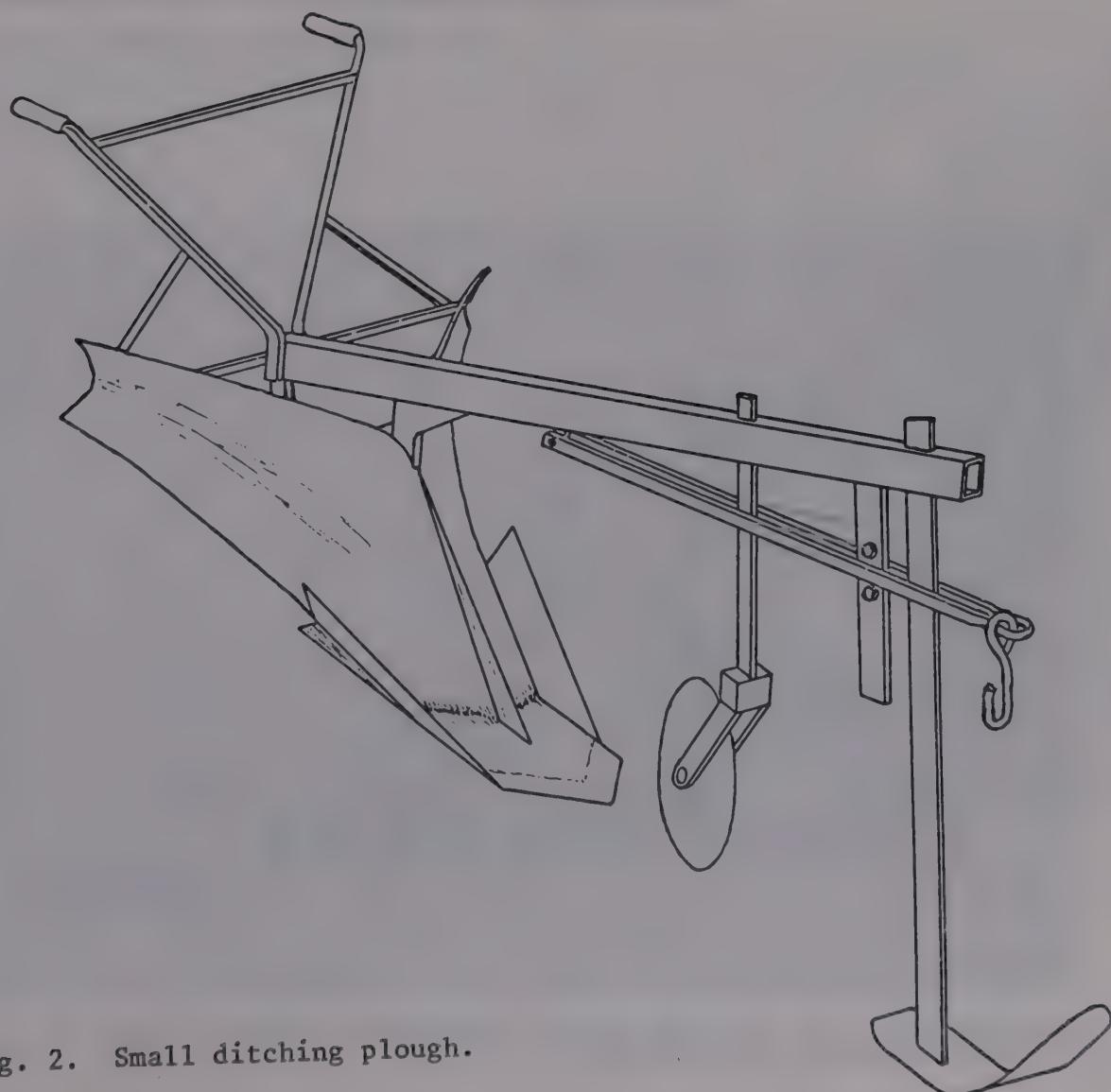


Fig. 2. Small ditching plough.

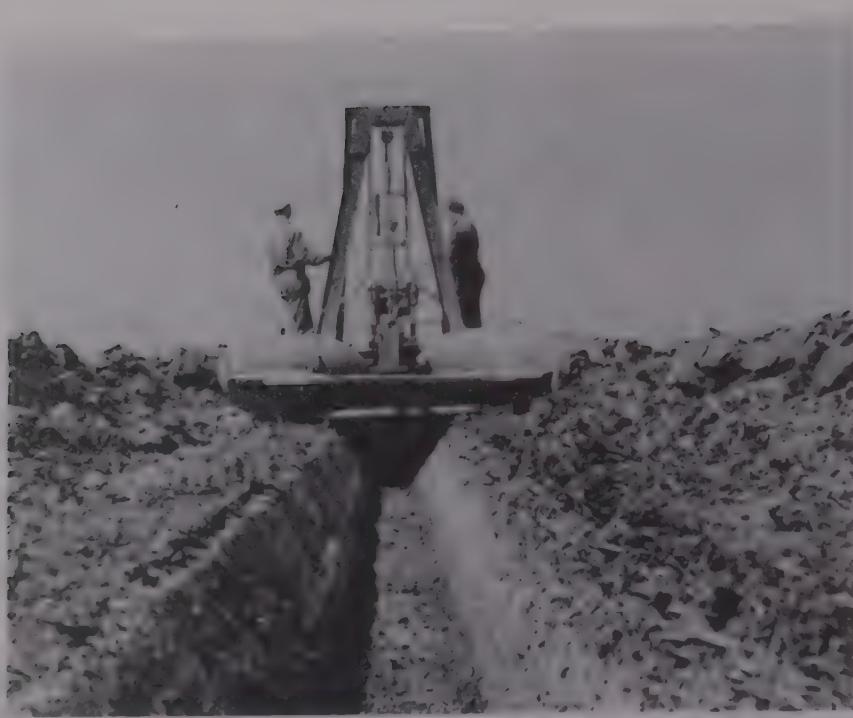


Fig. 3. Large furrow-type ditcher with wings for pushing the soil clear of the ditch.

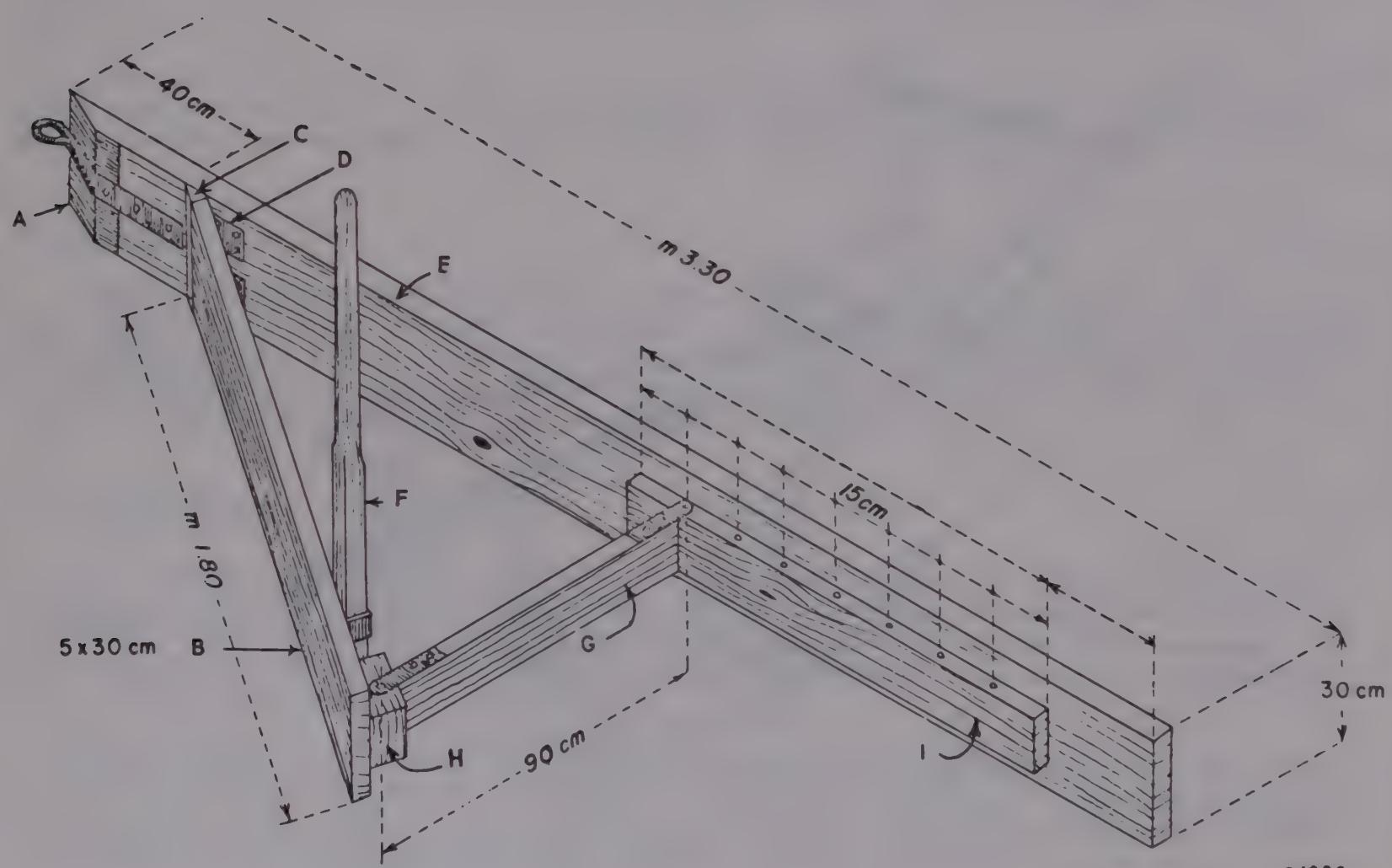


Fig. 4. Simple homemade drag ditcher.



Fig. 5. American V-type ditcher.



Fig. 6. Wheel excavator (backhoe)-loader, mounted on a farm tractor.



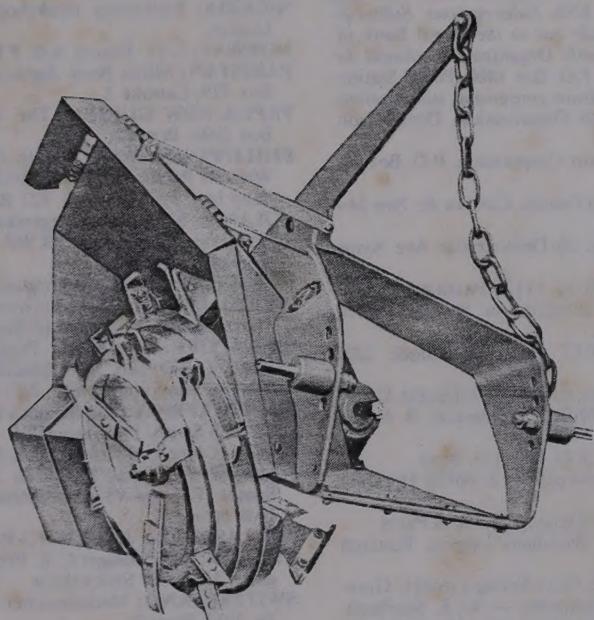
Fig. 7. Dragline with weed-cleaning bucket.



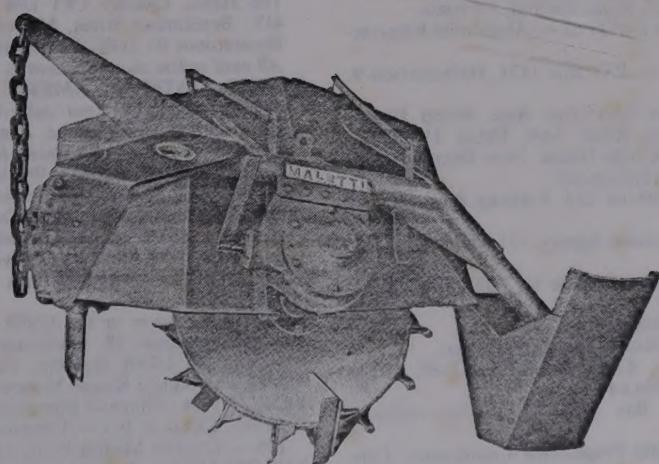
Fig. 8. Bucket-wheel trencher for installing plastic drain tubing.



Fig. 9. Off-highway truck.



for tractors of 35 - 45 HP



for tractors of 50 - 60 HP

Fig. 10. Rotary ditchers.

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